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Nesting habitat selection and productivity of northern goshawks in west-central Montana

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NESTING HABITAT SELECTION AND PRODUCTIVITY

OF NORTHERN GOSHAWKS

IN WEST-CENTRAL MONTANA

By

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ABSTRACT

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During the 1997 and 1998 nesting periods, I systematically surveyed for Northern Goshawks (*Accipiter gentilis*) using a randomized design across all available forest cover types in the northern Flint Creek Range in west-central Montana. The study was done to obtain an unbiased estimate of nest-site selection, quantify nesting habitat at five spatial scales (landscape, post-fledging family area, nest stand, nest-tree area, and nest tree proper), and compare the success and productivity of goshawk nesting attempts among habitats selected by goshawks. Nesting goshawks were limited in distribution by habitat availability within a narrow elevational zone, dependent on forest cover type (with Douglas-fir the preferred type), and selected for specific landscape and habitat characteristics at the five spatial scales evaluated. Results suggested that within an intensively managed landscape, goshawks selected a core area of mature forest (15 ± 3.6 ha) that was surrounded by denser, small-sized trees. At the post-fledging family area (PFA) scale, logistic regression predicted goshawk presence based on the proportion of land within the PFA that contained north aspects, high canopy closure, and fewer clearcut harvest areas. At the nest-stand scale, discriminant function analysis (DFA) separated occupied nest stands ($n = 19$) from random stands ($n = 30$) based on greater canopy closure, greater shrub cover, less wood litter, and greater density of large-sized trees; at the nest-tree area, greater total plant cover, canopy closure, large tree density, and less sapling density; and at the nest-tree, greater diameter at breast height and height to the lowest live limb. I also evaluated specific landscape and physiographic features associated with nests, and DFA separated occupied from random sites based on less distance from the nest to a forest opening, less distance from the nest to the edge of the nest stand, and lower elevations. Occupied nest sites were dependent on aspect with 82.6% of nests located on north slopes. The number of young fledged per nest was negatively correlated with the size of the nonforested opening near the nest and sapling densities in nest stands and was positively correlated with the density of large-sized trees in nest-tree areas. I suggest that well-designed management treatments that maintain large areas of mature forest and focus on reducing small-sized tree densities in the understory should be able to improve existing conditions for goshawks.

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Most of all, I thank my parents and children, Amber and Jason, for their support and pride in my choice to pursue a career in wildlife biology. I wish there was a way to thank my mother, who instilled in me a passion for wildlife and wild places but couldn't be on this earth long enough to see this project come to a close.

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INTRODUCTION

During the 1970s, concern developed in the western United States over the effects of timber harvest on wildlife species that depend on mature and old-growth forests. The Northern Spotted Owl (*Strix occidentalis caurina*) controversy exemplified the conflict between use of forests by humans and a need to manage for forest-dependent organisms (Yaffee 1994). More recently, public focus has shifted to concern for conservation of the Northern Goshawk (*Accipiter gentilis*). However, habitat relationships of the Northern Goshawk (hereafter "goshawk") remain poorly understood. In the western United States, mature and old-growth forests may be especially important to nesting goshawks (summarized in Daw et al. 1998). Thus, it makes biological sense to assume that any changes that reduce or alter large expanses of mature forest can reduce the number of suitable nest sites, lower reproductive success and recruitment, and disrupt population stability (Reynolds 1983, Crocker-Bedford 1990, Ward and Kennedy 1996).

Little is known about the goshawks response to forest management; understanding this phenomenon would take controlled experiments over extended periods of time. Furthermore, managers cannot predict the responses of organisms to perturbations nor design effective conservation strategies without understanding the processes that result in the distribution of wildlife populations. The availability of suitable habitat may limit the size of bird populations. Habitat suitability is a function of the structural characteristics and spatial arrangement of habitat patches, the presence of predators and competitors, and adequate food resources (Cody 1985). A course-filtered approach used to assess ecosystems (Hunter 1991) may miss important aspects of a particular habitat type, such as understory development. Conversely, studies that focus on microhabitat, which is a finefiltered approach, may omit important landscape patterns that contribute to population distribution. If birds select nesting habitat through a hierarchical process (Hildén 1965, Hutto 1985), the goal of studies of habitat selection should be to gain an understanding of this process by incorporating finer scales of investigation within courser scales (Wiens et al. 1987, VanderWerf 1993).

Researchers have addressed nest-site selection by goshawks at several spatial scales including (1) the nest tree, nest plot, and/or nest stand (Hayward and Escano 1989, Whitford 1991, Bull and Hohmann 1994, Lilieholm et al 1993, Squires and Ruggiero 1996); (2) the home range (Bright-Smith and Mannan 1994, Hargis et al. 1994, Kennedy et al. 1994, Patla 1997); and (3) the landscape level (Bosakowski and Speiser 1994, Johannson et al. 1994, Woodbridge and Detrich 1994). However, concerns have been raised that most of these studies have been characterized by an overall lack of randomized survey design (Siders and Kennedy 1996, Squires and Ruggiero 1996). Only two studies of nesting goshawks have been done in the Northern Rockies. In central Montana, Whitford (1991) assessed 12 previously known goshawk nest stands in Douglas-fir; and found that nests tended to be in mature forests, but were comprised of higher densities of smaller trees than found in old-growth Douglas-fir. Hayward and Escano (1989) summarized habitat characteristics in 0.04 ha circular plots centered on 17 previously known nest sites in northern Idaho and Montana. Neither of these studies used a randomized design and occupancy of nests by goshawks was not confirmed during the duration of these studies. At the onset of my study, the only study that I knew of that applied a randomized survey design was Squires and Ruggiero (1996) in southern

Wyoming. I followed their protocol in my study because a properly randomized design is the only way to obtain an unbiased estimate of goshawk nesting-habitat selection.

To assess the suitability of nesting habitat, we must first obtain a solid understanding of which cover types are occupied by goshawks, especially those cover types that result from human-induced change. Because the presence of a species does not necessarily mean that the occupied habitats are suitable, we must then proceed to measure correlates of fitness (i.e. fecundity, adult and juvenile survival) among the forest cover types that are occupied (VanHorne 1983, Hutto 1995). Such information is fundamental to understanding the effects of land management practices on wildlife.

STUDY OBJECTIVES

In the Northern Rockies (USFS Region 1), virtually nothing is known about goshawk distribution patterns, nest-site selection within landscapes, or nesting success and productivity. Region 1 of the USFS conducted an assessment of goshawk management across nine national forests and identified a need to study goshawk nest-site selection because management of goshawk habitat varies widely among these forests, is largely based on data from studies done in other regions, and because no systematic survey across a large area has ever been conducted in this region (Maj 1996). To fill this knowledge gap for a species of concern, I formulated the following study objectives:

1. Obtain an unbiased assessment of nest-site selection;

2. Quantify nest-site selection at five spatial scales (landscape, post-fledging family area, nest stand, nest-tree area, and nest tree proper) by comparing occupied sites with randomly located unoccupied sites;
3. Compare the success and productivity of goshawk nesting attempts among available habitats;
4. Evaluate goshawk food habits; and
5. Compare data on nest-site selection, nesting success, and productivity with data from other studies throughout the West to assess the relative suitability of goshawk nesting habitat in the Northern Rockies.

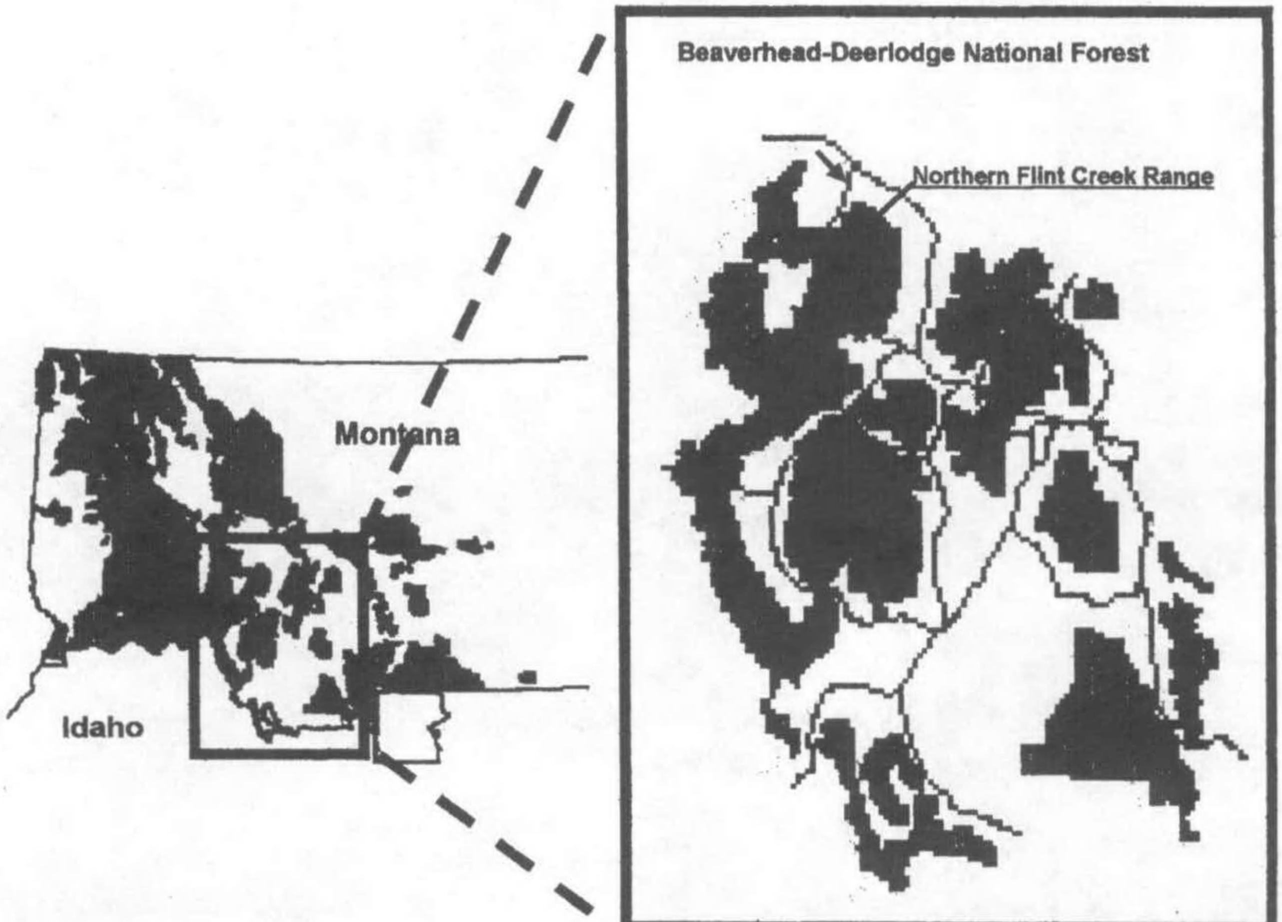
STUDY AREA

LOCATION

The study was conducted during the 1997 and 1998 breeding seasons in the northern half of the Flint Creek Range on the Beaverhead-Deerlodge National Forest, west-central Montana (Fig. 1). The Flints are surrounded by Interstate 90 (on the north and east sides) and state Highway 1 (on the south and west sides) between the towns of Drummond, Philipsburg, Anaconda, and Deer Lodge. The Flints geographically connect with the Anaconda Pintlar Wilderness to the south and the Sapphire Mountains to the west. The Clark Fork River separates the Flints from the Garnet Range to the north and the continental divide to the east.

The study area is defined as a 45,527-ha block that encompasses the entire northern half of the Flint Creek Range. I included all lands within the Beaverhead-

Figure 1. Map of the Beaverhead-Deerlodge National Forest including the study area in the northern half of the Flint Creek Range.



Deerlodge National Forest boundary that extend from the Montana State Prison Ranch boundary on the east to Wyman Gulch on the west and from private lands on the north to Goat Mountain on the south. Seven Bureau of Land Management (BLM) sections (S35 of T9N R11W, S6 and S8 of T7N R13W, and S16, S20, S30, and S31 of T8N R13W) and three private sections (S12 of T9N R12W and S7 and S17 of T9N R11W) that fall outside of the National Forest boundary also were included in the study area.

GENERAL CLIMATE, LANDSCAPE VEGETATION PATTERNS, DISTURBANCE HISTORY, AND CURRENT LAND MANAGEMENT

The study area ranges in elevation from 1,460 m to nearly 3,050 m. Climate is a mixture of weak Pacific maritime and continental systems, with annual precipitation ranging from 36 cm at lower elevations to more than 102 cm on the mountaintops. In general, dominant forest types include ponderosa pine (*Pinus ponderosa*)/Douglas-fir at lower elevations; Douglas-fir, lodgepole pine, and subalpine fir (*Abies lasiocarpa*) at middle elevations; subalpine-fir/engelman spruce (*Picea engelmanni*)/whitebark pine (*Pinus albicaulis*) at higher elevations; and the highest peaks dominated by rock and alpine vegetation. Forest zones are not discrete, such that, inland Douglas-fir grows on north-facing slopes with ponderosa pine often found at the same elevation on south-facing slopes. Lodgepole pine spans middle elevations where Douglas-fir is a late seral species and into higher elevations where subalpine fir is a late seral species (Losensky 1993). Whitebark pine, usually restricted to higher elevations, occurs in patches on ridge tops at middle elevations. The patchy distribution of forest types results in a landscape that consists of a complex mosaic of different cover types (Fig. 2, Table 1).

Since the mid-1800s, humans have altered native habitats from placer mining, livestock grazing, timber harvest, road construction, human habitation, and fire suppression (USFS 1995). Discovery of gold in the Gold Creek drainage in 1852 resulted in the removal of more than $20,000,000 in gold from surrounding gulches, with the last large mining company leaving the area in 1940 (Stuart 1977). Early unregulated grazing altered plant communities in natural grassland openings, riparian zones, and forested areas. Early timber harvest methods consisted of high-grading that removed the largest trees, followed by clear-cutting in the 1960s that converted large expanses of forest to younger seral stages and fragmented contiguous stands of old growth. The most noticeable result was an overall decline in the amount of mature and old-growth Douglas-fir and ponderosa pine (Habeck 1990, USFS 1995).

Fire suppression, which began in the Flints in the 1870s, has further altered this landscape. For example, quaking aspen (*Populus tremuloidies*) and ponderosa pine, both fire-dependent species, are less prevalent (Hejl 1992; USFS 1995, 1996). Many Douglas-fir stands, where the fire-free interval once ranged from 10 to 31 years, have developed dense thickets of saplings that now endanger the older trees (i.e. reduced growth and vigor, increased susceptibility to insect and disease infestations, increased susceptibility to crown fire through fuel "laddering") (Arno 1980, 1995). Lodgepole pine stands generally developed through stand-replacement fires occuring every 150 to 250 years. Some lodgepole pine stands were open grown in nature and are currently dominated by

Figure 2. Distribution of forest cover types in the northern Flint Creek Range

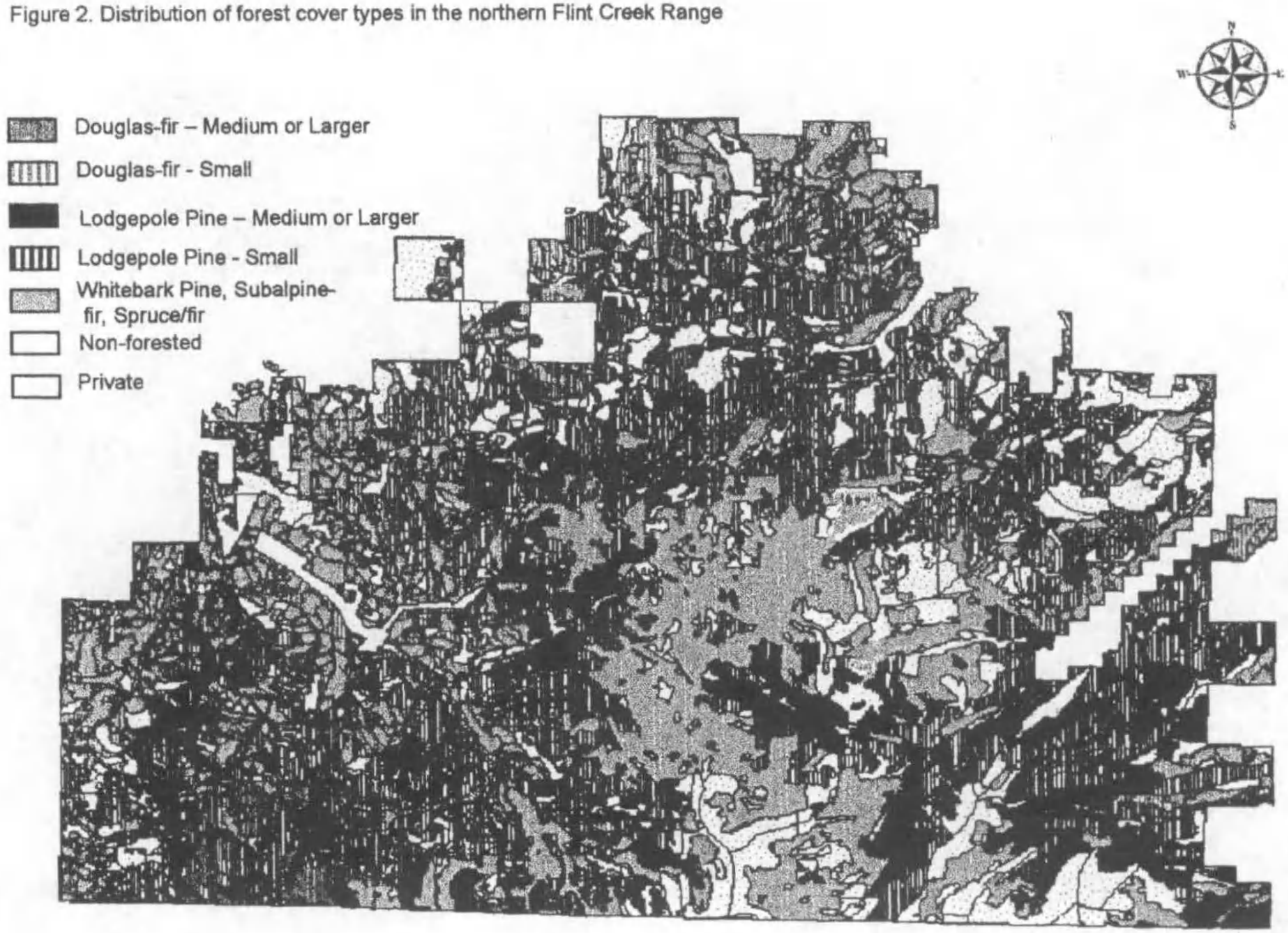


Table 1. Total land base (ha) within the study area (45,528 ha) and within the area actually surveyed (28,469 ha) comprised of each forest cover type.

Forest cover type[a]	Study area (%)		Survey area (%)	
Lodgepole small	11,031	(24.2)	7,260	(25.5)
Lodgepole medium or larger	5,896	(13.0)	4,746	(16.7)
Douglas-fir small	1,366	(3.0)	2,727	(9.6)
Douglas-fir medium or larger	8,113	(17.8)	5,737	(20.2)
Subalpine fir, whitebark, Spruce-fir[b]	6,488	(14.3)	3,755	(13.2)
Aspen	46	(0.1)	28	(0.1)
Nonforested openings[c]	6,328	(13.9)	1,167	(4.1)
Seedlings/saplings	2,732	(6.0)	1,708	(6.0)
Private land (unclassified)	3,528	(7.8)	1,341	(4.7)

[a] Size classes: 12.71 to 22.86 cm dbh = small; > 22.86 cm dbh = medium or larger.
[b] Includes all size classes.
[c] Aspen, water, talus or rock, wet meadows, and dry meadows.

large diameter trees: such stands now contain dense thickets of Douglas-fir saplings in the understory. Other lodgepole pine stands of similar age are less open-grown and contain higher densities of smaller diameter trees that have become decadent with age and pose a risk of a catastrophic fire event.

METHODS

SURVEY UNITS

Using GIS Arcview, I constructed a grid that divided the 45,527-ha study area into 290 survey units (each 805 x 1,950 m; Squires and Ruggiero 1996) laid side-by-side across the landscape. I eliminated 30 units because they contained a large proportion (> 50%) of high-elevation talus slopes with little vegetative cover. Of the 260 remaining survey units, I randomly selected 125 that I grouped into 25 blocks containing an average of five survey units each. I then randomly selected a block and surveyed all units within the block. Each unit was sampled by pacing two parallel transects 800 m in length (Kennedy and Stahlecker 1993) and placed 260 m apart, with broadcast calling stations every 300 m (Joy et al. 1994), for a total of seven calling stations per transect. To maximize coverage of broadcasts within each survey unit, broadcast stations were staggered by 150 m on adjacent transects (Joy et al. 1994). I then randomly selected the starting location for the first transect along the short axis of the survey unit to account for variation in the landscape (Squires and Ruggiero 1996).

Based on 1997 data, I intensified survey efforts in 1998 to increase the probability of detection during what appeared to be the peak calling period for the study area (from 1

June to 10 July). Prior to 1 June, I checked all nest stands that were active in 1997 for reoccupancy. Reoccupied sites were eliminated from 1998 surveys by placing a 1-km radius circular buffer around the nest (this totaled 6 survey units). The remaining 119 units from the 1997 effort were resurveyed in 1998. An additional 56 units were randomly selected from the remaining units. I then grouped the 175 total units into 35 blocks containing five survey units per block and conducted surveys according to 1997 procedures.

The amount of land surveyed within each forest cover type was nearly proportional with its availability within the study area (Table 1). Because several different cover types of various patch shapes and sizes often comprised one survey unit, it was impossible for the total ha within each cover type surveyed to be in exact proportion to availability on the landscape. The small percentage of area actually surveyed within nonforested openings reflects, for the most part, the omission of high-elevation rock slopes.

GOSHAWK SURVEYS AND RESPONSES

Goshawk surveys were conducted using broadcast-calling methods according to established protocol (Kennedy and Stahlecker 1993, Joy et al. 1994). When a goshawk responded, surveyors recorded the transect and station number, date, time, general habitat response type (vocal non-approach, silent approach, vocal approach) compass bearing, and estimated the distance to the responding hawk. Responses, sightings, or vocalizations from other raptor species were recorded in the same manner. All goshawk responses were followed immediately by a thorough search within an approximately 300-m radius of the response area (generally, the maximum distance a nesting goshawk will respond; Joy et al. 1994). If a nest was not found after a reasonable search effort (3 to 4 hours), surveyors moved on to the next survey unit. When a nest was located, I placed a buffer around the nest (approximately 1-km wide, depending on topography) and eliminated the buffered area from further survey. In this way, territoriality was accounted for and disturbance to the nest was minimized.

NEST MONITORING AND BANDING OF NESTLINGS

I monitored all nests on a weekly basis until the young fledged or the nest failed. In 1997, I banded all chicks in each nest 19 to 27 days after the estimated hatching date. This allowed for more accurate assessment of the number of chicks that hatched, as well as age, sex, and the condition of the young. In 1998, I banded chicks at only 6 of the 13 nests because of time constraints. The number of chicks that hatched, their age, and the condition of the young at the remaining nests were assessed through weekly visits to nests.

CALCULATING ONSET OF INCUBATION, HATCHING DATE, AND FLEDGING DATE

For 1997 and 1998, I determined the fledging date, or date the young attained flight, by counting forward 39 days from the mean hatching date (Boal 1994) and the onset of incubation by backdating 32 days (Reynolds and Wight 1978) from the mean hatching date.

CALCULATING PRODUCTIVITY AND NEST SUCCESS

I calculated productivity by determining the mean number (± SE) of young that successfully fledged from each nest per year, then calculating an overall mean for both years. Nesting success for each year and an overall mean for both years was calculated using program Contrast (Hines and Sauer 1989) following Mayfield (1975). Daily survival rates were based on a 32-day incubation period (egg survival) and a 39-day nestling period (nestling survival) (Reynolds and Wight 1978, Boal 1994). No nests were located during the egg-laying period.

CALCULATING NEST DENSITY

Following Woodbridge and Detrich (1994), I calculated nest density by dividing the total number of occupied nests in 1998 (13) by the total ha surveyed in 1998 and converted nest density to reflect number of occupied nests per 1,000 ha surveyed.

PREY COLLECTION AND ANALYSIS

On a weekly basis, I collected prey remains and pellets from "plucking" sites in the vicinity of the nest as well as from under the nest. I identified mammalian and avian prey by comparison with specimens in the University of Montana's Philip L. Wright Zoological Museum, and with skull keys. Prey remains were tallied following Boal and

Mannan (1994). Biomass for mammalian species was calculated using the average adult mass of museum specimens that had been collected in western Montana. I obtained avian prey biomass from Dunning (1984) and Johnsgard (1990).

QUANTIFYING HABITAT CHARACTERISTICS

I studied habitat selection of goshawks by comparing habitat use at five spatial scales. In descending order, the spatial scales were (1) the landscape level; (2) post-fledging family area; (3) nest stand; (4) nest-tree area; and (5) nest tree proper. Variables measured within each scale were chosen based on the forest structural components widely used by management agencies to classify and manage forested environments as well as components that proved significant in goshawk studies elsewhere. Methods used for measuring variables were a combination of those used by the USFS and those used in other studies throughout the West. I collected all habitat data after goshawk chicks had fledged from the nest to minimize disturbance. Habitat variables recorded at each spatial scale and methods used to measure each variable are listed in Appendix A. Each scale is defined below.

Landscape level.— Defined as the entire 45,527-ha study area.

Post-fledging family area.— Defined as a 170-ha area circle centered around the nest tree (delineated in GIS Arcview using the buffer command). Reynolds et al. (1992) and Kennedy et al. (1994) describe an area of concentrated use or post-fledging family area (PFA) around the nest used by the goshawk family during the 30- to 50-day fledgling-dependency period. Because the PFA provides hiding cover and prey for fledglings to develop hunting skills, management activities that reduce the percentage of mature forest over time may affect fledgling survival. Conversely, lack of disturbance over time may reduce availability of prey.

Nest stand.— The nest stand represents the patch of trees comprised of homogeneous species, age, and size-class distributions wherein goshawks select a tree to nest in. A forest stand is also the fundamental unit land managers use to distinguish and manage forest patches of different cover types on the landscape.

All forest stands in the Flints have been mapped using GIS Arcview, and stand classification data are available in the USFS TSMRS data base files (dbf). Stand boundaries are mapped using a blend of ground-truthing procedures, photo interpretation analysis, and satellite imagery, then digitized into shape files in GIS Arcview, and joined with habitat characteristics recorded in dbf files. The degree of detail for stand data entered into dbf files varies depending on the type of stand exam or ground-truthing procedure conducted. For instance, in areas classified as unsuitable for timber harvest, stands have been characterized into forest cover types based on photo interpretation only. Conversely, in areas that are managed for timber harvest, more comprehensive ground-truthing procedures were employed (J. Goffney, pers. comm.).

To ensure consistency, I personally classified all stands by first delineating the perimeter in the field and then averaging variables measured in approximately eight sample plots within each nest stand. I selected the number of sample plots for each stand based on photo interpretation stratum, size of the stand, and the minimum number of plots generally needed to maintain a low standard error for basal area (S. Gerdes, pers.

comm.). Plots were evenly spaced throughout the stand using a chain-grid overlay to obtain a consistent classification (C. Fiedler, pers. comm.). To locate plots in the field, I navigated (using a USGS topographic map and compass) to a known reference point and used a compass and meter tape to find each sample point.

Nest-tree area.— Defined as a 0.04-ha circular plot (11.3-m radius) divided into four quadrants, one transect extending from north to south and one from east to west with the nest tree at the plot center.

Nest tree.— At occupied nest trees, the nest tree is the tree in which the goshawk nested.

RANDOM POINTS FOR EVALUATION OF NEST-SITE SELECTION

To gain a solid understanding of habitat characteristics important to goshawks, random points were located only in the forest cover types used by goshawks. Assuming that goshawks nested only in Douglas-fir and lodgepole pine forest types, I randomly selected 30 points within the area that I searched for nests. Forest types not used by goshawks were not sampled (subalpine fir, whitebark pine, nonforested openings, and regeneration harvest units in the seedling-sapling stage).

Random UTM coordinates were used to generate random points. I then evaluated each random point in the order of selection by overlaying the cover type GIS/Arcview layer (developed by the USFS). A point was considered if it fell within a cover type used by goshawks and was not inside an occupied nest stand. I navigated (using a USGS topographic map and compass) to a known reference point and used a compass and meter tape to find each random point. The tree closest to the random point was considered the random nest tree. The random point was considered plot center for the nest-tree area and PFA scale. Boundaries for random, unoccupied stands were delineated in the same manner as occupied nest stands. All data-collection procedures used at active nest sites within the five spatial scales were applied to random sites.

STATISTICAL ANALYSIS

I analyzed all data using a personal computer with SPSS software version 9.0 for Windows (Norusis 1998), except for data on nesting success (see above). Statistical analyses of productivity, nesting success, diet, and habitat data (Appendix A) are detailed below.

Productivity, nesting success, and diet.— Data on productivity, nesting success, and diet were analyzed by individual year, and then pooled to obtain two-year means. I tested for between-year differences in productivity and diet using Mann-Whitney *U*-tests (Sokal and Rohlf 1995). Differences in nestling daily survival rates between years were ascertained using a chi-square test (Hines and Sauer 1989).

Is nest-site selection independent of forest cover type?— Following Neu et al. (1974) and Byers et al. (1984), I used a chi-square goodness-of-fit test to test the hypothesis that goshawk nest location is independent of forest cover type. To reduce the number of cells with expected frequencies < 5, the original eight cover types (Table 1) were combined into three: (1) lodgepole pine small-sized and larger; (2) Douglas-fir small-sized and larger; and (3) "other." Availability or "expected use" was determined by calculating the proportion of the total survey area comprised of each forest cover type. Actual use was determined by calculating the proportion of nests found only during 1997 and 1998 random surveys comprised of each forest cover type ($n = 19$). Bonferonni simultaneous confidence intervals were used to determine whether use of each cover type was greater than (+), less than (-), or in proportion to (ns) availability on the landscape.

Goshawk nest distribution spatial analysis.— In GIS/Arcview, I overlaid nest UTM point coordinates on the cover type layer to create a map displaying goshawk nest distribution across the study area. Distribution patterns were statistically evaluated, first, through use versus availability analysis at the Landscape Level (described above), and second, by determining if any landscape and physiographic features (Appendix A) distinguish areas occupied by goshawks from random, unoccupied areas (see below). The distance from nests to the grassland forest interface, nearest road, permanent water source, and nonforested opening, and the size of nearest nonforested opening was calculated in GIS/Arcview and the dbf data-summary files downloaded into SPSS for analysis.

Are there any habitat characteristics measured at the landscape, PFA, nest-stand, nest-tree area, and nest-tree scales that distinguish areas occupied by goshawks from unoccupied areas located within the same forest cover type?— I first tested for univariate differences between occupied and random sites at each spatial scale (i.e. *t*-tests, Mann-Whitney *U*-tests, ANOVA, and paired *t*-tests for continuous variables; chi-square independence tests for categorical variables). Habitat data for each year were pooled. Prior to univariate analysis, the natural log or arcsine transformation was used to normalize data, where appropriate. I constructed bivariate correlation matrices for each spatial scale to identify linear relationships among variables within occupied and random, unoccupied sites.

For landscape and physiographic features, nest-stand, nest-tree area, and nest-tree scales, I used discriminant function analysis (DFA) to determine habitat characteristics that best separated occupied nest sites from random sites (Huberty 1994). The DFA model-building process involved three major phases to reduce the total number of original variables to a parsimonious, biologically meaningful subset of variables.

In phase one, I entered all original variables (ranging from 10 to 18) into a full DFA model for initial evaluation and screening. A correlation matrix was constructed to identify colinearity problems, and logical and statistical screening procedures were used to evaluate variables for possible exclusion (Huberty 1994). Variables with correlations greater than 0.6 were screened (Bosakowski and Speiser 1994) so that one of the two correlated variables was removed, and the remaining variable allowed to represent both variables, or in some cases, one variable could represent a group of variables.

In the phase two, I entered the reduced model from phase one (8 to 11 variables) into stepwise DFA. Variable selection was based on maximizing the Mahalanobis distance between occupied and random sites while maintaining a type I error rate of 0.10 for entry. Box's *M* criterion was used to test for homogeneity of covariance. I used separate covariance matrices for classification, although in some instances, matrices were heterogeneous.

Phase three consisted of selecting a final DFA model. To ensure that the best subset of variables indeed resulted from stepwise selection, I evaluated the relative contribution of each variable from the phase-two model. Removing and reentering each variable, removing those variables that contributed little to explaining the model, and rerunning various combinations of variable subsets, accomplished this. In most cases, the stepwise selection procedure indeed produced the best subset of variables that were biologically meaningful and resulted in maximum separation between occupied and random sites. Final model classification results and chi-square values (which test for differences between group centroids) were used as an index to DFA model significance. I plotted the frequency distributions of discriminant scores to demonstrate the separation between occupied and random sites, the pattern of overlap that resulted from misclassified sites, and the direction of trend for discriminating variables. I also plotted probability distributions for discriminant scores to illustrate the probability that a site was random.

At the PFA scale, I used stepwise logistic regression to determine which variables were most important in goshawk presence/absence (Manly et al. 1993). I plotted the probability distribution to illustrate the probability of goshawk presence/absence, the direction of trend for important variables, and misclassified sites.

Goshawk nesting productivity relative to habitat structure.— I first evaluated the unsuccessful nests by examining the habitat data to identify any distinctive characteristics related to cover type (i.e. Douglas-fir versus lodgepole pine) or the logistic regression and DFA analysis (i.e. misclassified sites). I used Spearman rank correlation to identify significant associations between the number of young that fledged per nest and forest cover type as well as habitat variables (including discriminant scores and logistic regression probabilities) at five spatial scales.

RESULTS

GOSHAWK SURVEYS

Search effort.— For 1997 and 1998 combined, I completed 4,200 broadcast calling stations covering 28,469 ha, or 70% of the 45,528-ha study area. Of the total area surveyed, 70% was covered two years in a row to increase the probability of finding goshawk nests that may have been missed the first year. The time spent surveying for goshawks totaled 2,160 person-hours.

Goshawk responses and located nests.— For 1997 and 1998 combined, 24 goshawks responded to broadcast calls. The estimated distances from which nesting goshawks responded ranged from 20 to 300 m. Responses included 15 alarm calls followed by approaches from nesting females, one alarm call with no approach from a nesting female, six silent approaches (thought to be males), one alarm call from a male apparently startled at close range, and one alarm call from a male near an active nest.

I located 19 goshawk nests, 16 through broadcast calling methods (1 to 38 days posthatching) and three through 1998 stand-reoccupancy checks (7 to 13 days before hatching). On average, 113.7 person-hours were required to find one goshawk nest.

Goshawk nest density.— Nest density for 1998 was one nest per 2,189.9 ha surveyed or 0.46 nests per 1,000 ha surveyed.

Responses, sightings, or nest locations of other raptor species.— Three Cooper's Hawks (*Accipiter cooperii*) responded to the broadcast goshawk alarm call: two silent approaches and one alarm call from a nesting female 25 m from the surveyor. One Sharp-shinned Hawk (*Accipiter striatus*) and two Cooper's Hawk nests were located incidentally during goshawk survey work. Distances from these four nests to the nearest known active goshawk nest ranged from 3.22 to 4.83 km.

Red-tailed Hawks (*Buteo jamaicensis*) responded to broadcast goshawk alarm calls more often than any other raptor species (including goshawks), with 34 responses total. To avoid double-counting Red-tailed Hawk responses, I placed a circular buffer (1.61-km diameter) around each response site, and counted all responses within the buffered area as one; therefore, the total number, 34, is conservative. During mid-April (pre-nesting) on one occasion, I observed a pair of goshawks "escorting" a Red-tailed Hawk from a goshawk nest stand. No physical contact was observed. On six occasions at six separate nests, a Red-tailed Hawk responded to an alarm call from a live goshawk after observers had flushed the adult female goshawk from her nest. In all cases, the Red-tailed Hawk stayed in the vicinity until observers left the nest area and the female goshawk became silent.

I observed 10 adult Great Gray Owls (*Strix nebulosa*) in the study area, three of which were found nesting in old goshawk stick nests 125 to 550 m from an active goshawk nest. In 1997 and 1998, a Great Gray Owl nested in the same aspen tree (in a mature lodgepole pine stand) that had been occupied by a goshawk in 1996. A goshawk nested in a separate (but adjacent) stand 350 m to the northeast in 1997 and 550 m to the northeast in 1998. In 1998, I discovered a Great Gray Owl incubating in an old goshawk nest (in a Douglas-fir tree, Douglas-fir dominant stand). At the same time, I observed a goshawk pair bringing sticks to a nest just 125 m west in the same stand. Nesting goshawks had also occupied the stand in 1997 with evidence indicating (i.e. 5 alternate nests) occupancy during several previous years. On two occasions, the goshawk was observed approaching the owl nest and the adult female Great Gray Owl was observed driving the goshawk away. The Great Gray Owl successfully fledged three young, and the goshawk fledged four young.

Three Great Horned Owls (*Bubo virginianus*), which are known to prey on young goshawks (Boal and Mannan 1994, Woodbridge and Detrich 1994), were heard within occupied goshawk PFAs over the two-year study period.

GOSHAWK PRODUCTIVITY, NEST SUCCESS, NESTING CHRONOLOGY, AND BANDING

Average number of young fledged per nest.— Over the two-year period, I monitored a total of 18 goshawk nests once per week until the young fledged or the nest failed. A total of 46 goshawks successfully fledged from 16 of the 18 nests, for an overall mean of 2.56 ± SE of 0.27 young fledged per nest. Productivity differed significantly between years (Mann-Whitney $U = 12$, $P = 0.017$), with a higher number of young fledging per nest in 1998 (mean = 2.92 ± 0.31) than in 1997 (mean = 1.83 ± 0.40).

In 1997, 11 nestlings successfully fledged from five of the six nests monitored (2 fledglings in 4 nests, and 3 in 1 nest). The sixth nest failed when the nestlings were approximately nine days old. Two nestlings were found dead in the nest with no sign of predation and were thought to have died from exposure, although other causes of failure (i.e. abandonment, starvation) could not be ruled out.

In 1998, 35 nestlings successfully fledged from 11of the 12 nests monitored (4 fledglings from 3 nests, 3 from 7 nests, and 2 from 1 nest). The 12th nest failed approximately 14 to 17 days posthatching. Three chicks were found dead in the nest with no sign of predation and may have died from exposure, abandonment, or starvation.

In 1998, three juveniles from three separate nests were found dead in the nest stand one to two weeks postfledging. In all cases, the carcasses were plucked clean, with feathers and bones left within a 1-m area, indicative of Great Horned Owl predation (R. Reynolds, pers. comm.), but this could not be confirmed.

Mayfield nesting success.— Over the two-year period, Mayfield (1975) nesting success was 67.3% (62.2% in 1997 and 72.9% in 1998). Daily nestling survival rates did not differ between years (0.994 ± 0.004 in 1997 and 0.996 ± 0.004 in 1998; $\chi^2 = 0.005$, df = 1, $P = 0.771$). Of the 18 nests monitored, the two-year estimated daily survival rate of eggs was 1.000, of nestlings 0.995 ± 0.004, and the overall estimated daily survival rate was 0.995 ± 0.003. Because I did not observe nests during the four-day egg-laying period, a daily survival estimate was not available for this period.

Nesting chronology.— The overall estimated mean onset of incubation was 5 May ± 1.42 days (range from 21 April to 14 May); hatching date, 6 June ± 1.42 days (22 May to 15 June); and fledging date, 12 July ± 1.42 days (29 June to 23 July).

Nesting chronology differed between years (Mann-Whitney $U = 5.0$, $P = 0.002$). Onset of incubation occurred 10 days earlier in 1998 than in 1997, perhaps due to mild weather. In 1997, mean onset of incubation was 10 May ± 1.53 days (range from 4 to 14 May); hatching, 11 June ± 1.53 days (5 to 15 June); and fledging, 17 July ± 1.53 days (13 to 23 July). In 1998, mean onset of incubation occurred on 30 April ± 1.93 days (range from 21 April to 9 May); hatching, 1 June (22 May to 10 June); and fledging, 7 July (29 June to 18 July).

Banding effort and band returns.— In 1997, 11 goshawk chicks (6 females, 5 males) from five of the six monitored nests were banded in the nest 19 to 28 days posthatching. In 1998, 12 chicks (6 females, 6 males) from five of the 12 monitored nests were banded. On 23 November 1998 (approximately 139 days postfledging), #1807-69220, which I banded as a nestling female on 23 June 1998, was captured and released by a falconer near Belgrade, Montana, approximately 160 km south/southeast from its natal nest.

GOSHAWK DIET

For 1997 and 1998 combined, I identified 101 prey items, 8 mammal and 10 bird species, from the prey remains collected at nests (Table 2). In 1997, the three most common prey species were, in descending order of abundance, snowshoe hare (*Lepus*

Table 2. Prey species frequency distribution. Table shows mammalian and avian prey species, the frequency (%) of each prey item for 1997 and 1998, and the percent of total biomass (1997 and 1998 combined) for each prey item.

Prey species	1997 Frequency (%)		1998 Frequency (%)		Total Biomass (%)
Mammals					
Snowshoe hare (*Lepus americanus*)	12	(32)	3	(5)	53.39
Mountain cottontail rabbit (*Sylvilagus nuttallii*)	1	(3)	0	(0)	1.11
Columbian ground squirrel (*Spermophilus columbianus*)	6	(16)	11	(17)	9.45
Golden-mantled ground squirrel (*Spermophilus lateralis*)	1	(3)	0	(0)	0.55
Red squirrel (*Tamiasciurus hudsonicus*)	7	(19)	26	(41)	14.27
Northern flying squirrel (*Glaucomys sabrinus*)	1	(3)	2	(3)	0.95
Northern pocket gopher (*Thomomys talpoides*)	1	(3)	1	(2)	0.57
Vole (*Microtus* sp.)	1	(3)	4	(6)	0.39
Total number of mammal prey items	30	(82)	47	(73)	80.69
Birds					
Blue Grouse (*Dendragapus obscurus*)	1	(3)	4	(6)	11.57
Ruffed Grouse (*Bonasa umbellus*)	0	(0)	2	(3)	2.56
Northern Flicker (*Colaptes auratus*)	0	(0)	3	(5)	0.94
Gray Jay (*Perisoreus canadensis*)	1	(3)	4	(6)	0.79
Clark's Nutcracker (*Nucifraga columbiana*)	1	(3)	2	(3)	0.90
Common Raven (*Corvus corax*)	0	(0)	1	(2)	1.95
Townsend's Solitaire (*Myadestes townsendi*)	1	(3)	0	(0)	0.08
American Robin (*Turdus migratorius*)	1	(3)	0	(0)	0.18
Dark-eyed Junco (*Junco hyemalis*)	1	(3)	0	(0)	0.06
Unknown small bird sp.	1	(3)	1	(2)	0.24
Total number of bird prey items	7	(18)	17	(27)	19.27
Total number of prey items	37		64		

americanus), red squirrel (*Tamiasciurus hudsonicus*), and Columbian ground squirrel (*Spermophilus columbianus*). In 1998, the three most common prey species included red squirrel, Columbian ground squirrel, and an equal number of voles (*Microtus* sp.), Blue Grouse (*Dendragapus obscurus*), and Gray Jays (*Perisoreus canadensis*). Overall, mammals contributed 81.0% of the total prey biomass and birds the remaining 19.0% (Table 2). In terms of biomass, the most important prey species were snowshoe hares, red squirrels, Blue Grouse, and Columbian ground squirrels.

HABITAT ANALYSIS

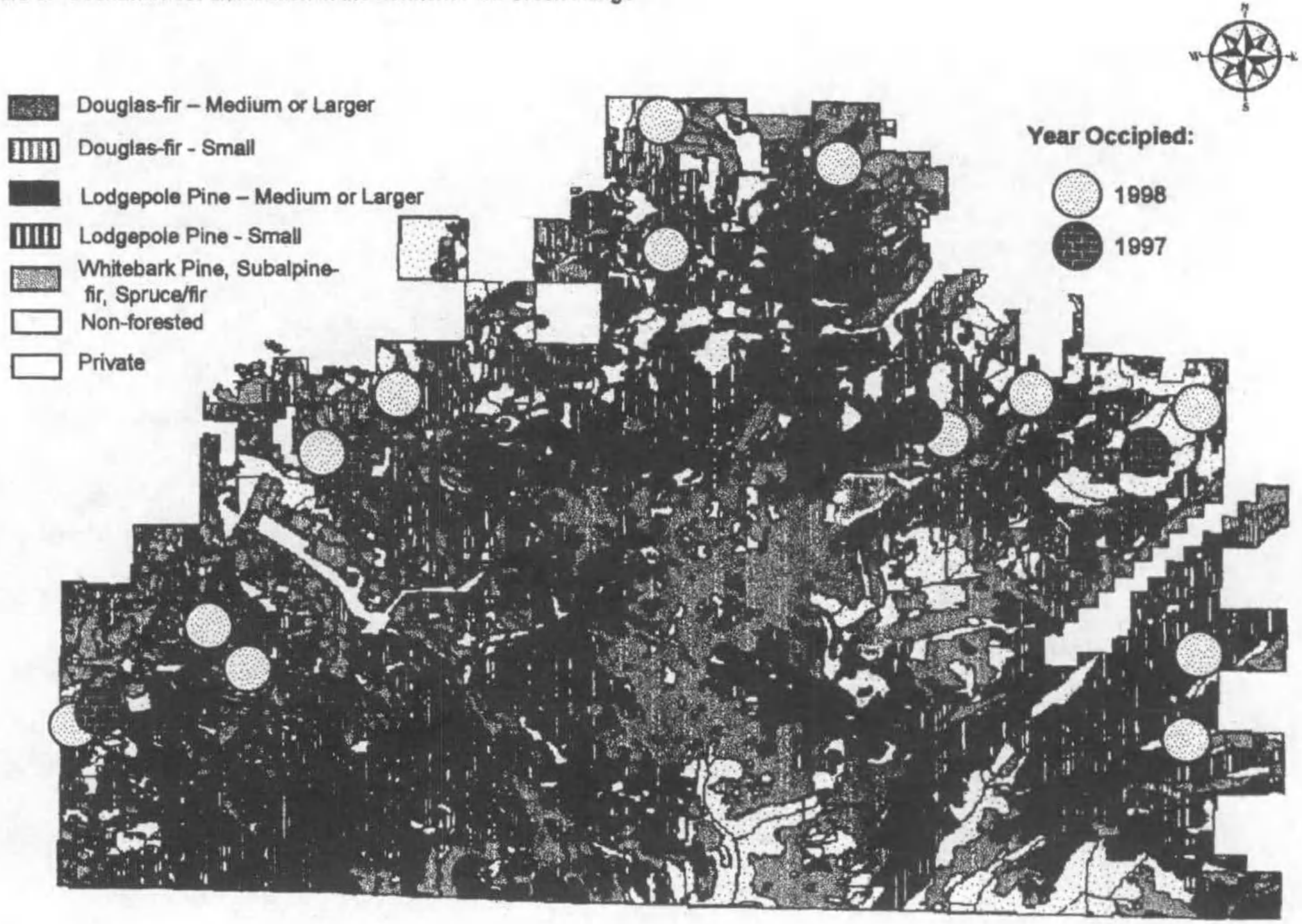
Goshawk distribution patterns.— In general, goshawks nested in either Douglas-fir (57.9%) or lodgepole pine (42.1%) forest cover types with overstory trees comprised of pole-sized or larger size classes (Table 3). Although we surveyed nearly 70.0% of the interior forest across the entire northern half of the Flint Creek Range (25 km^2 of which was in a roadless area), all goshawk responses were received and all nests found around the periphery of the study area within 1 to 5 km of the grassland/timber interface (Fig. 3). Nests were distributed 2 to 5 km apart at elevations from 1,524 to 2,012 m, with 82.6% of nests located on north aspects. Nests in lodgepole pine cover types were located at the lower elevational extent where lodgepole pine occurs, whereas nests in Douglas-fir were found throughout the elevational range of Douglas-fir. The forested lands that goshawks occupied, adjacent to the grassland/forest interface, have been heavily influenced by timber harvest, associated road building, land exchanges, and livestock grazing (USFS 1995, 1996, 1997) relative to habitats at higher elevations in the forest interior.

Table 3. List of broad forest cover types in the northern Flint Creek Range. Table shows the number and percent of the total goshawk nests found in each cover type during 1997 and 1998 random surveys (n = 19), and the percent of the total area surveyed comprised of each.

Forest cover type[a]	No. of nests (%)		% of survey area
Douglas-fir small	1	(5.3)	9.6
Douglas-fir medium or larger	10	(52.6)	20.2
Lodgepole small	6	(31.6)	25.5
Lodgepole medium or larger	2	(10.5)	16.7
Subalpine-fir/Spruce-fir/Whitebark (all size classes)	0	(0.0)	13.2
Non-forest (meadow, aspen, rock)	0	(0.0)	4.1
Seedling/saplings	0	(0.0)	6.0
Private Land (unclassified)	0	(0.0)	4.7

[a]Size classes: 12.71 to 22.86 cm dbh = small; > 22.86 cm dbh = medium or larger.

Figure 3. Goshawk nest distribution in the northern Flint Creek Range



Is nest-site selection independent of forest cover type?— Use versus availability analysis indicated that goshawk nest-site selection was dependent on forest cover type at the landscape level. Goshawks nested selectively in Douglas-fir (57.9% of nests), used lodgepole pine (42.1%) in proportion to availability, and avoided all other forest cover types (0.0% of nests) ($\chi^2 = 10.41$, df = 3, $P < 0.007$) (Table 4).

Are there any habitat characteristics measured the landscape, PFA, nest-stand, nest-tree area, and nest-tree levels that distinguish areas occupied by goshawks from unoccupied areas located in the same forest cover type?— Discriminant function analysis clearly indicated that goshawks selected nest sites nonrandomly relative to specific landscape features and/or structural characteristics at the landscape, nest-stand, nest-tree area, and nest-tree scales. Differences between occupied and random sites were highly significant with little overlap occurring between the two groups. At the PFA scale, logistic regression predicted goshawk presence/absence based on habitat composition; however, the degree of overlap with random sites was high. Univariate and multivariate (DFA or logistic regression) results for each hierarchical scale are detailed, in descending order, below.

Landscape and physiographic features relative to nest-site selection.— On average, goshawks selected nest sites that were lower in elevation ($t = -2.80$, df = 51, $P = 0.007$) and near the edge of the nest stand ($t = -6.80$, df = 51, $P < 0.001$) (Table 5). In addition, selection of nest sites was dependent on aspect (Fisher's exact test, $P = 0.015$), with 82.6% of occupied nest sites (19 out of 23) occurring on north-facing slopes versus only 43.3% for random sites (Table 6). Nest-site selection was independent of position

Table 4. Goshawk use versus availability analysis at the landscape level in the northern Flint Creek Range. Use is based on 19 nests found during random surveys in 1997 and 1998. Availability is based on the proportion of the total land area surveyed composed of each forest coverl type. To reduce the number of cells with expected frequencies < 5, the total number of cover types was reduced from the eight listed in Table 1 to three (Douglas-fir = small and medium or larger size classes combined, lodgepole pine = small and medium or larger size classes combined, and other = all other cover types combined).

Forest cover type	Expected usage (E_i)	Observed usage (O_i)	Expected proportion of usage (P_{io})	Actual proportion of usage (P_i)	Bonferonni intervals for P_i	Usage
Douglas-fir	5.65	11.00	0.297	0.579	$0.308 \leq P1 \leq 0.850$	+
Lodgepole pine	8.01	8.00	0.422	0.421	$0.115 \leq P2 \leq 0.692$	NS
Other	5.34	0.00	0.281	0.000	$-0.271 \leq P3 \leq 0.271$	-

Table 5. Goshawk landscape and physiographic features scale, univariate results for continuous variables, northern Flint Creek Range. *P*-values < 0.006 represent significant differences after applying Bonferroni adjustments for multiple comparisons.

Variable	Occupied nest sites ($n = 23$)			Random sites ($n = 30$)			
	Mean	SE	Range	Mean	SE	Range	*P*
Distance to water (m)[a]	1130.57	486.86	18-11670	471.57	65.99	50-1309	0.347
Distance to nearest nonforested opening (m)[a]	299.00	41.84	35-750	370.70	167.75	28-5160	0.087
Size of nearest nonforested opening (ha)[a]	16.96	3.65	1-61	1701.38	1122.00	1-24281	0.180
Distance to nearest road (m)							
Open year round only[a]	774.00	109.98	28-2262	554.20	82.44	22-1982	0.078
Seasonal or open year round[a]	382.92	39.18	28-690	531.03	82.91	22-1982	0.229
Distance to edge of nest stand (m)[a]	100.65	9.27	15-200	254.23	9.26	100-450	<0.001
Slope	28.91	3.13	5-55	30.03	3.13	8-77	0.805
Elevation (m)	1731.79	27.55	1524-2012	1832.43	27.55	1567-2121	0.007

[a]Values log-transformed for analysis, although untransformed means and SE are reported here.

Table 6. Landscape and physiographic features contingency analysis for categorical variables.

	Occupied nest sites ($n = 23$)		Random sites ($n = 30$)				
	Observed	Expected	Observed	Expected	χ^2	df	P[a]
Aspect							
North	19.0	13.9	13.0	18.1			
South	1.0	1.3	2.0	1.7	--		0.015
East	1.0	4.8	10.0	6.2			
West	2.0	3.0	5.0	4.0			
Type of opening							
Natural	16.0	13.5	15.0	17.5	2.05	1	0.152
Clearcut	7.0	9.5	15.0	12.5			
Position on slope:							
Lower 1/3	9.0	9.1	12.0	11.9			
Middle 1/3	7.0	6.5	8.0	8.5			0.976
Upper 1/3	5.0	5.6	8.0	7.4	--		
Saddle	2.0	1.7	2.0	2.3			

[a] P-value reported from Fisher's exact test.

on the slope (Fisher's exact test, $P = 0.976$, Table 6), and distance from the nest to the nearest permanent water source did not differ from random ($P = 0.347$, Table 5).

The goshawk's strong association with one edge of the nest stand could not be evaluated adequately in the absence of a cluster analysis to account for all stands or patches of forest adjacent to the nest stand because the number of adjacent stands varied widely (from 3 to 9). Of the 19 stands occupied by nesting goshawks, 17 of the nearest adjacent stands consisted of open-grown forest (7 stands dominated by small-sized trees and 10 by medium or larger-sized trees), and 2 of dense forest. All 19 of the nearest adjacent stands had canopy closures > 50%, with Douglas-for the dominant tree species for 13 stands and lodgepole pine for 6. Of the furthest adjacent stands, 10 were comprised of dense small-sized lodgepole pine, seven were regenerating clearcuts < 40 years in age, and two were large open grassland parks. The nearest adjacent stands for random, unoccupied sites was not ascertained.

Goshawks chose nest sites closer to nonforested openings than random (mean = 299.00 ± 41.84 m for occupied; mean = 370.70 ± 167.75 m for random); however, the difference was not significant (Mann-Whitney $U = 249.5$, $P = 0.087$) owing to the high variation within groups (range from 35 to 750 m for occupied sites and 28 to 5,160 m for random). The mean size of these nonforested openings was 16.96 ± 3.65 ha for occupied sites and 1,701.38 ± 1,122.00 ha for unoccupied sites. Here again, the difference was not significant ($t = -1.36$, df = 51, $P = 0.180$) because of the high variation in random sites (range from 0.40 to 61 ha for occupied sites and 0.40 to 24,281 ha for random) (Table 5). Yet, for occupied sites, forest openings near nests tended to be smaller ($r = 0.565$,

$P = 0.005$). Conversely, random sites exhibited no correlation between these two landscape features ($r = 0.343$, $P = 0.064$). Nonforested openings at occupied sites were comprised of 70.0% small meadows and only 30.0% clearcut logging units. However, when compared with random sites (50.0% meadows, 50.0% clearcut logging units), the difference was not significant ($\chi^2 = 2.05$, df = 1, $P = 0.152$) (Table 6).

The final DFA model clearly separated occupied from random sites based on Distance to Edge of Nest Stand, Distance to Nonforested Opening, Elevation, and Aspect (87.0% of occupied sites classified correct and 93.3% of random correct) (Figs. 4 and 5). The group centroids (-1.31 for occupied sites and 1.01 for random) were significantly different ($\lambda = 0.42$, $\chi^2 = 42.36$, df = 4, $P < 0.001$). Covariance matrices were homogenous (Box's $M = 15.29$; $P = 0.175$), and 57.9% of the variation in the model was explained by between-group differences (canonical correlation = 0.761).

The full DFA model included 11 variables (Appendix A) for initial evaluation and screening (87.0% of occupied sites classified correct and 93.3% of random correct). Distance to Any Road was eliminated because it was highly correlated ($r = 0.880$) with Distance to Roads Open Year-Round Only, and 10 of the original 11 variables were entered into a stepwise selection DFA. Stepwise selection reduced the full model to three variables (Distance to Edge of Nest Stand, Elevation, and Distance to Nonforested Opening) (82.6% of occupied classified correct and 93.3% of random correct) (Table 7). I then reentered Aspect in the final model because it increased classification results for occupied sites and was important statistically during univariate analysis (Table 6).

Figure 4. Landscape and physiographic features final model discriminant function analysis showing frequency distributions of canonical discriminant function scores for (A) occupied nest sites ($n = 23$) and (B) random sites ($n = 30$). Discriminating variables are: Distance to the Edge of the Nest Stand, Distance to Nearest Nonforested Opening, Elevation, and Aspect. Horizontal arrows indicate the direction of the trend for each variable. Group centroids are marked by vertical arrows (↓).

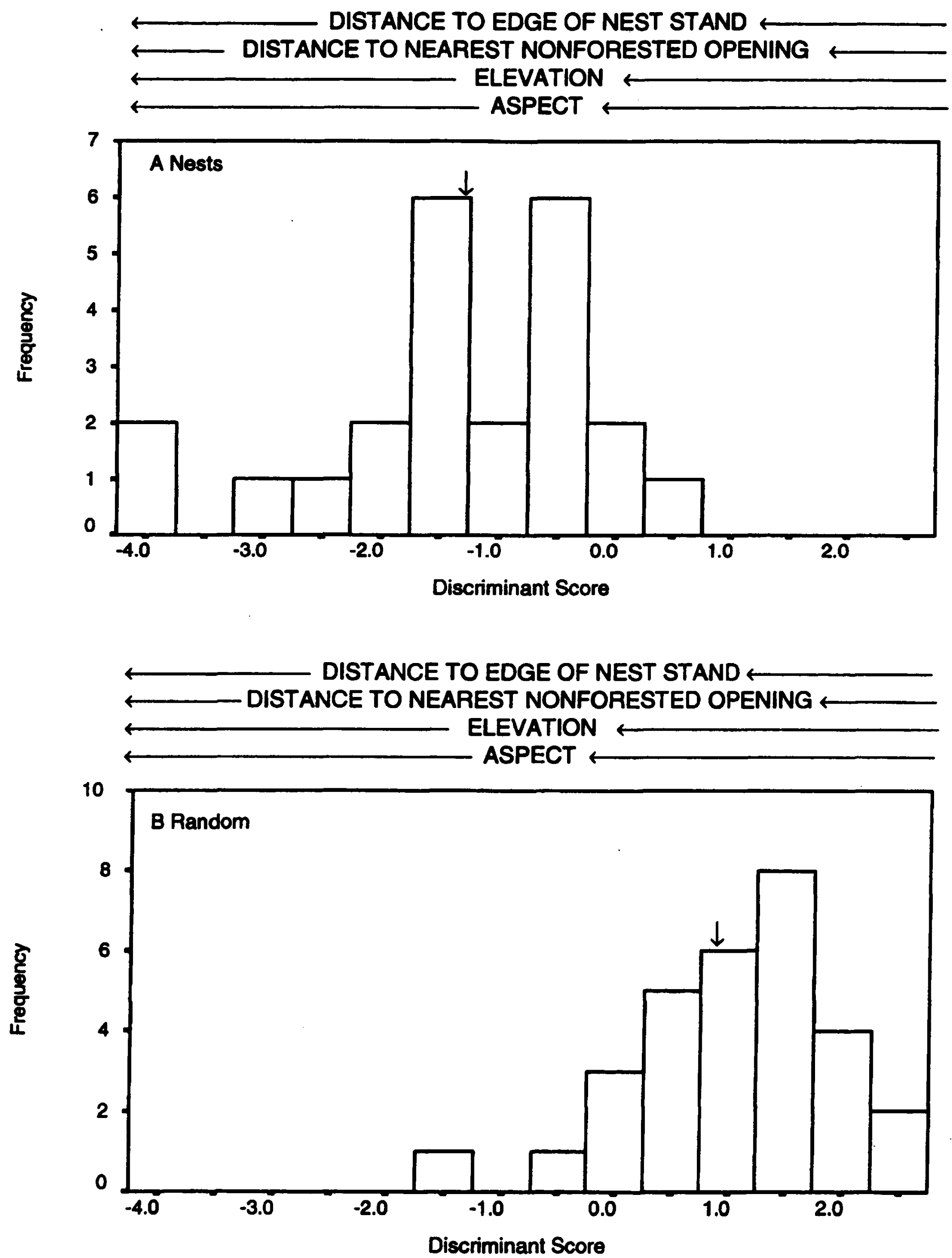


Figure 5. Landscape and physiographic features final discriminant function analysis showing the probability distribution for discriminant scores ($n = 23$ for occupied nest sites, $n = 30$ for random sites). Data indicate the probability that a nest site is random. Mean probabilities are marked with a vertical arrow (↓), and circled cases represent misclassified sites.

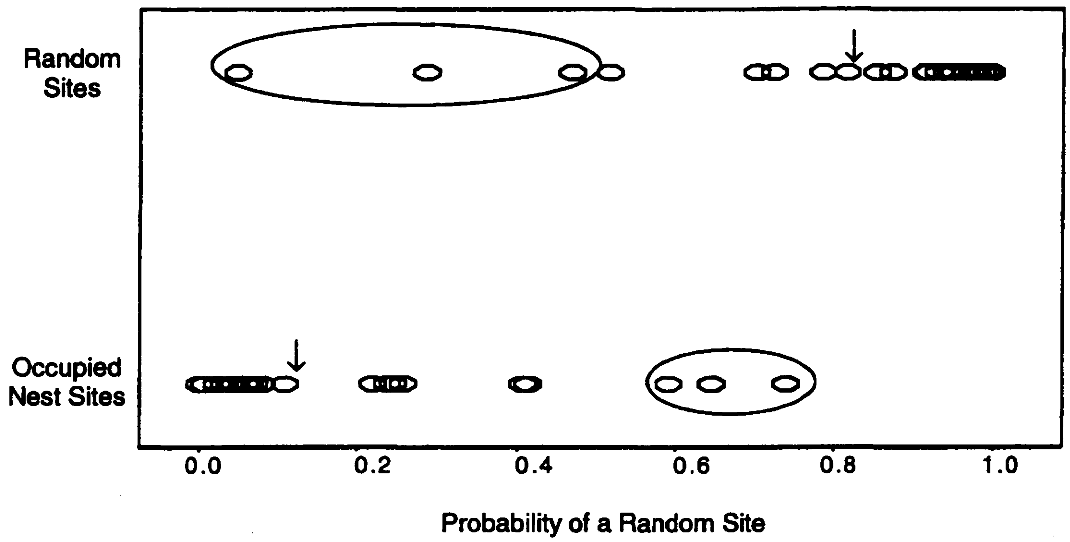


Table 7. DFA stepwise selection results for each of four spatial scales (landscape and physiographic features, nest stand, nest-tree area, and nest tree). Table shows discriminating variables, canonical discriminant function coefficients (Bs), and *F*-test results for each step.

Scale discriminating variables	Canonical discriminant function coefficients (Bs)	No. of variables	*F*	*P*
Landscape and physiographic features				
(constant)	-12.802			
ln(distance to edge of nest stand)	-1.747	1	46.29	<0.001
elevation	-0.003	2	27.41	<0.001
ln(distance to neareast nonforest opening)	0.379	3	20.80	<0.001
aspect[a]	-0.251	4		
Nest-stand				
(constant)	-4.789			
arcsin(canopy closure)	4.832	1	10.42	<0.001
ln(wood litter)	-1.074	2	6.87	<0.001
ln(shrub cover)	0.929	3	7.19	<0.001
ln(density of large-sized trees)	0.520	4	8.35	<0.001
Nest-area				
(constant)	-4.865			
ln(sapling density)	-0.426	1	11.38	0.001
ln(plant cover)	1.364	2	9.45	<0.001
ln(density of large-sized trees	0.257	3	8.63	<0.001
arcsin(canopy closure)	2.382	4	7.69	<0.001
Nest-tree				
(constant)	-8.768			
ln(diameter at breast height)	1.828	1	24.76	<0.001
ln(height to lowest live limb)	0.164	2	18.70	<0.001
tree species	0.744	3	17.95	<0.001

[a]Variable not included in stepwise selection DFA, therefore *F*-test statistics are not available. Variable was included in the final model.

PFA scale.— On average, 77.0% of PFAs occupied by goshawks were covered by forest, 11.3% (19 ha) of which was dominated by medium or larger-sized trees (or mature forest), and 65.7% (112 ha, 62 ha lodgepole pine and 50 ha Douglas-fir) small-sized trees (Table 8). The 19 ha of medium or larger-sized trees represented, for the most part, the nest stand (see below) or a core area of mature forest surrounded by small-sized trees. On average, canopy closure was high, such that 68.9% of the PFA contained forest with > 50% canopy closure and 8.9% with 25 to 50% canopy closure. Nonforested areas were comprised of 9.3% (16 ha) regenerating clearcuts (< 40 years old) and 6.7% (11 ha) natural meadows.

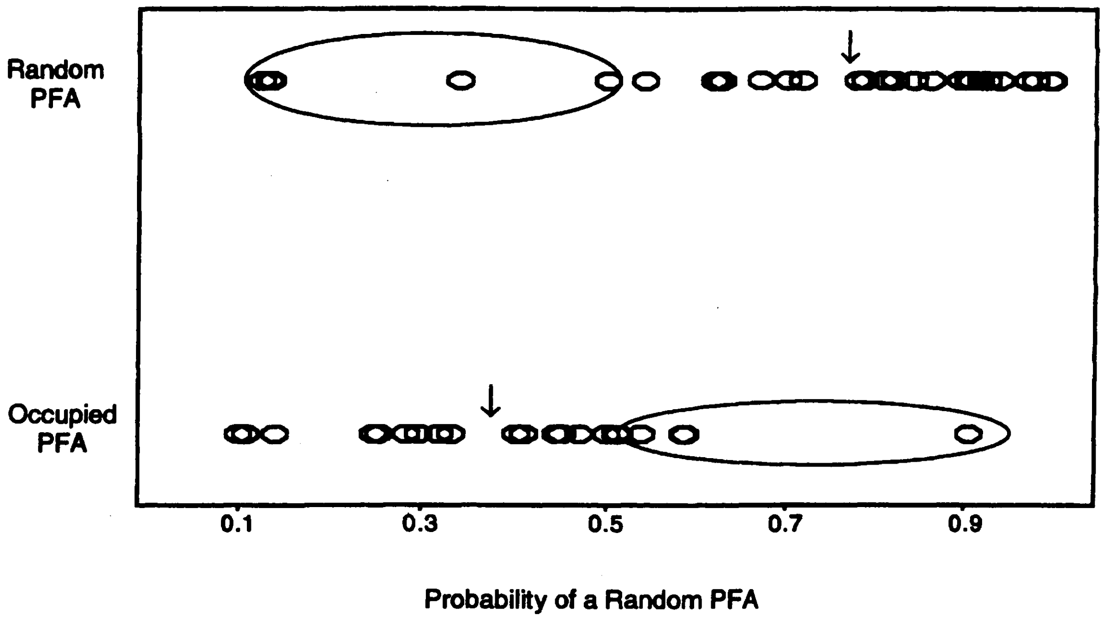
Compared with random, occupied PFAs contained more area with north aspects (Mann-Whitney $U = 174.50$, $P = 0.020$) and less area with low canopy closure (Mann-Whitney $U = 165.00$, $P = 0.033$). However, P-values < 0.003 would be considered highly significant after applying Bonferonni adjustments for multiple comparisons. None of the remaining 16 variables analyzed were significantly different (Table 8).

Logistic regression predicted goshawk presence/absence based on more area with North aspects, more forested area with high tree canopy closure (> 75%), and fewer clearcut harvest units (68.4% of occupied PFAs classified correct and 82.8% of random correct) ($\chi^2 = 21.17$, $P < 0.001$). The mean probability that an occupied PFA was classified as random was high (0.398) (Fig. 6). However, all model coefficients were significant at the 0.050 level (coefficients: North Aspect = -8.210, Clearcut Logging Units = 12.820, High Crown Closure = 4.070). The constant term was excluded because it was not significant, and its omission increased classification results.

Table 8. Univariate results for PFA scale analysis. Data represent the mean proportion of the PFA comprised of Each variable, the standard error (SE), and range. *P*-values are from Mann-Whitney *U* tests.

	Occupied PFAs (n = 19)			Unoccupied PFAs (n = 29)			
Variable	Mean proportion	SE	Range	Mean proportion	SE	Range	*P*
Forest cover type							
Lodgepole (all size classes)	0.375	0.072	0.000-0.940	0.382	0.050	0.001-0.938	0.841
Douglas-fir (all size classes)	0.395	0.065	0.000-0.909	0.295	0.049	0.000-0.879	0.217
Subalpine-fir/whitebark	0.010	0.006	0.000-0.107	0.014	0.005	0.000-0.079	0.367
Medium or larger trees	0.113	0.026	0.000-0.343	0.115	0.021	0.000-0.350	0.857
Small trees	0.657	0.050	0.242-0.987	0.607	0.032	0.325-0.938	0.268
Seedling/sapling	0.093	0.029	0.000-0.379	0.129	0.029	0.000-0.477	0.352
Meadow, aspen	0.067	0.022	0.000-0.294	0.084	0.013	0.000-0.260	0.190
Crown closure classes							
Low < 25%	0.162	0.047	0.000-0.579	0.237	0.028	0.000-0.483	0.033
Medium 25 to 50%	0.089	0.035	0.000-0.605	0.064	0.022	0.000-0.587	0.957
Medium high 50 to 75%	0.146	0.033	0.000-0.512	0.117	0.019	0.000-0.396	0.650
High > 75%	0.543	0.069	0.062-0.987	0.536	0.036	0.069-0.906	0.620
Slope angle classes							
Low < 20%	0.215	0.056	0.000-0.682	0.220	0.047	0.000-0.820	0.975
Medium 20 to 40%	0.513	0.061	0.155-0.958	0.539	0.046	0.071-0.980	0.712
High > 40%	0.212	0.056	0.000-0.811	0.213	0.046	0.000-0.804	0.966
Aspect class							
North	0.619	0.037	0.274-0.854	0.449	0.049	0.000-0.905	0.020
East	0.118	0.031	0.000-0.421	0.099	0.025	0.000-0.426	0.309
South	0.129	0.032	0.000-0.524	0.214	0.032	0.000-0.576	0.058
West	0.073	0.019	0.000-0.315	0.153	0.028	0.000-0.563	0.081
Unclassified	0.060			0.085			

Figure 6. PFA logistic regression analysis final model. Data represent predictive value distribution for random ($n = 29$) and occupied ($n = 19$) PFAs and indicate the probability that a PFA is random. Mean probabilities are marked with a vertical arrow (↓), and misclassified PFAs are circled. Predictive variables are: North Aspect, Clearcut Logging Units, and > 75% Crown Closure. Circled areas represent misclassified PFAs.



Nest-stand scale.— In general, goshawks nested in multi-storied stands (4 to 5 canopy layers) dominated by Douglas-fir (57.9%) or lodgepole pine (42.1%) with the overstory comprised of mature trees (medium or larger size class). Only 15.8% (3 of 19) of occupied stands (2 Douglas-fir and 1 lodgepole pine) exhibited characteristics indicative of old growth (i.e. multi-storied stands, open grown, with large-diameter trees dominant in the overstory). Occupied nest stands were smaller in size (t = -2.32, df = 47, P = 0.025), contained a higher density of large trees (38.10 to 50.80 cm dbh; t = 2.762, df = 46, P = 0.008), greater canopy closure (t = 2.95, df = 47, P = 0.005), and greater shrub cover (t = 2.77, df = 46, P = 0.008) (Table 9). In contrast, unoccupied stands exhibited higher total tree density (t = -2.17, df = 47, P = 0.032), higher densities of small-sized trees (12.71 to 22.86 cm dbh) (t = -2.27, df = 47, P = 0.028), less overall plant cover (t = 3.02, df = 47, P = 0.004), and more wood litter (t = -2.45, df = 47, P = 0.020) (Table 9). A high percentage of occupied stands (94.7%) was composed of multiple (4 to 5) canopy layers (versus only 60.0% for unoccupied stands) (Fisher's exact test, P = 0.012) (Table 10). No logging activity in the past 100 years had occurred in 68.4% of the occupied nest stands whereas 31.6% had received some type of selective thinning (3 stands 21 to 99 years ago, and 3 stands 0 to 21 years ago). However, the timing since logging activity in occupied stands did not differ from that in random stands (P = 0.877, Table 10). The final DFA model clearly separated occupied from random nest stands based on Canopy Closure, Shrub Cover, Wood Litter, and Density of Large Trees (78.9% of occupied classified correct and 90.0% of random correct) (Figs. 7 and 8). Group centroids (1.138 for occupied and –0.721 for random) were significantly different (λ = 0.54, χ^2 = 27.52,

Table 9. Goshawk nest-stand scale univariate results for continuous variables. Data based on mean stand characteristics for 19 occupied stands and 30 random stands (mean number of plots per stand = 9). A + or – following *P*-values < 0.050 indicate the direction of observed trend. *P*-values < 0.003 represent significant differences based on Bonferroni adjustments for multiple comparisons.

	Occupied nest stand (n = 19)			Random stand (n = 30)			
Variable[a]	Mean	SE	Range	Mean	SE	Range	*P*
Stand Size (ha)	15.42	3.60	2-60	16.80	2.48	3-65	0.750
Mean tree height (m)	19.73	0.54	16-23	18.17	0.64	7-23	0.094
Mean live height (m)	9.41	0.52	4-13	8.32	0.58	2-14	0.197
Total tree density (trees/ha)[b]	1503.15	190.11	377-3425	2218.13	260.46	568-5336	0.032-
Saplings[b]	560.40	128.48	0-1903	1051.44	230.80	0-4646	0.070
Small[b]	588.23	101.62	23-1581	885.61	89.79	112-2128	0.028-
Medium[b]	308.73	27.21	117-666	251.11	27.56	0-577	0.045+
Large[b]	37.61	7.51	0-101	22.00	5.98	0-117	0.008+
Extra-large[b]	8.18	5.98	0-27	7.96	2.83	0-57	0.079
Basal area (m sq./ha)	41.79	1.71	28-57	41.61	1.99	9-57	0.951
Canopy closure (%)[c]	66.70	1.73	48-82	58.21	2.30	26-76	0.011+
Shrub cover (%)	53.45	3.89	23-85	37.52	4.25	1-91	0.013+
Plant cover (%)	68.46	2.94	41-84	53.61	3.43	25-90	0.004+
Forb cover (%)[b]	16.69	2.80	4-56	12.72	1.46	1-30	0.175
Grass cover (%)	33.73	4.04	2-62	33.40	3.30	0-63	0.529
Wood litter (%) (> 2.54 cm)[b]	10.36	1.51	0-22	14.27	1.18	3-27	0.011-
Seedlings (0.04 ha plot)[b]	44.68	11.99	0-200	29.54	7.17	0-195	0.858
Snags per ha (> 12.7 cm dbh)	9.27	3.52	0-60	7.70	4.23	0-100	0.795

[a]Tree density size classes: saplings = < 12.71 cm dbh, small = 12.71 to 22.85 cm dbh, medium = 22.86 to 38.10 cm dbh, large = 38.11 cm dbh to 50.80, and extra-large = > 50.80 cm dbh.
[b]Values log-transformed for analyses, although untransformed means and standard errors (SE) are reported here.
[c]Values arcsin-transformed for analyses; untransformed means and SE reported here.

Table 10. Goshawk nest-stand scale contingency analysis results for categorical variables.

Variable	Occupied Nest Stands (n = 19)		Random Stands (n = 30)		P[a]
	Observed	Expected	Observed	Expected	
Number of canopy layers					
2	0.0	0.8	2.0	1.2	
3	1.0	4.3	10.0	6.7	
4	8.0	8.1	13.0	12.9	0.012
5	10.0	5.8	5.0	9.2	
Logging activity					
None in past 100 years	13.0	13.2	21.0	20.8	
21 to 99 years ago	3.0	3.1	5.0	4.9	1.000
0 to 21 years ago	3.0	2.7	4.0	4.3	

[a] P-value reported from Fisher's exact test.

Figure 7. Goshawk nest-stand scale final model discriminant function analysis showing frequency distributions of canonical discriminant function scores for (A) occupied nest stands (n = 19) and (B) random stands (n = 30). Discriminating variables are: Canopy Closure (%), Shrub Cover (%), Wood Litter (%), and Density of Large-sized Trees (trees/ha 22.86 to 38.10 cm dbh). Horizontal arrows indicate the direction of the trend for each variable. Group centroids are marked by vertical arrows (↓).

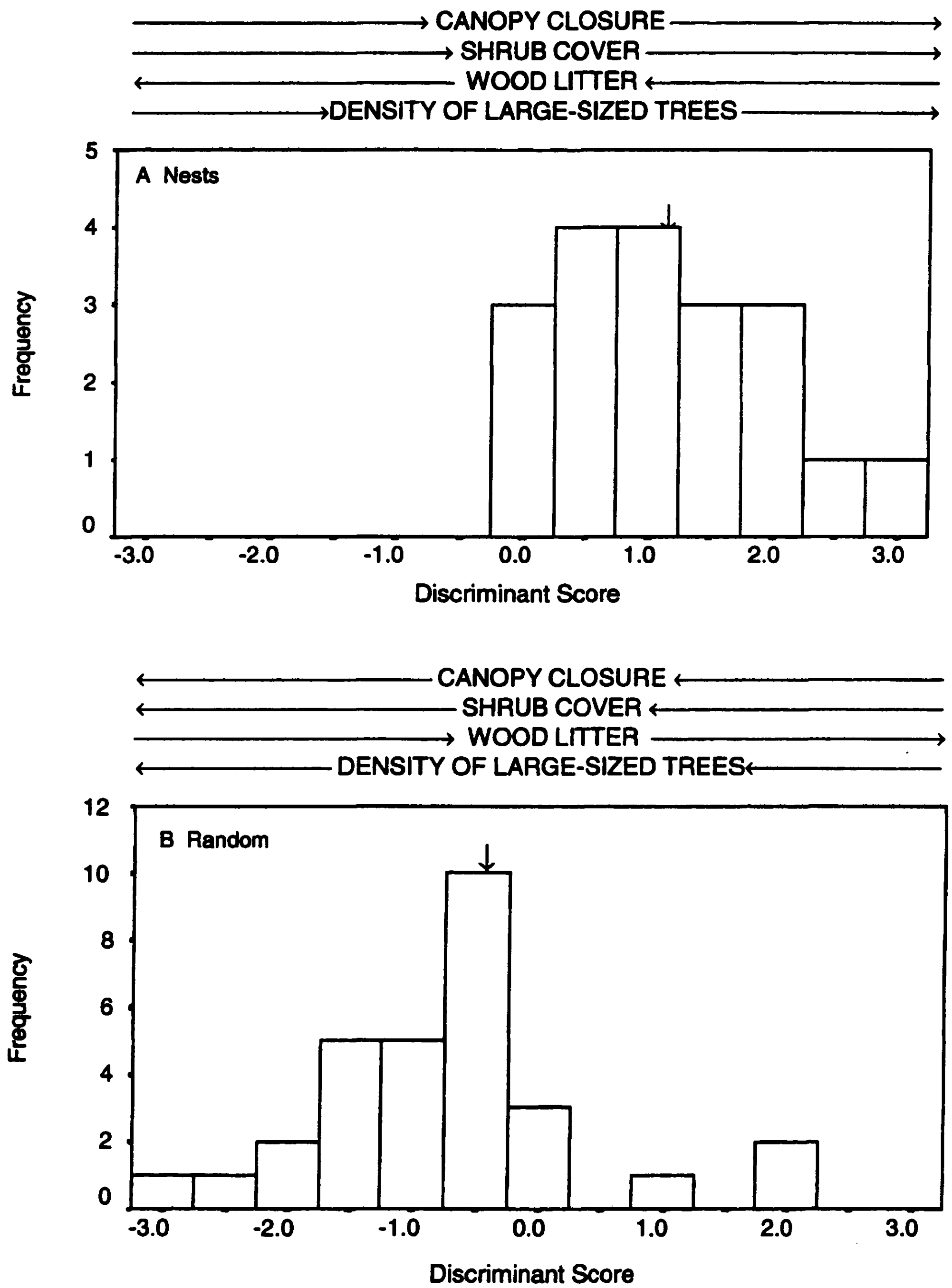
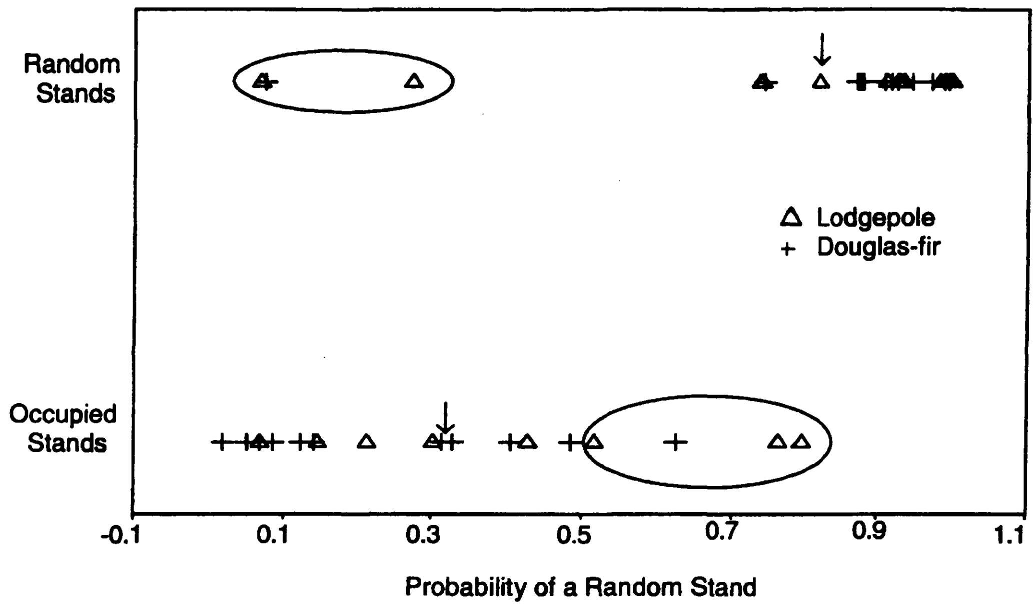


Figure 8. Goshawk nest-stand scale final model discriminant function analysis showing the probability distribution of discriminant scores ($n = 19$ for occupied stands, $n = 30$ for random stands). Data indicate the probability that a stand is random. Mean probabilities are marked with a vertical arrow (↓), and circled cases represent misclassified stands.



$P < 0.001$). Between-group differences explained 45.7% (canonical correlation = 0.676) of the variation in the model, and covariance matrices were heterogenous (Box's M = 29.19; $P = 0.005$).

The full DFA model included all 17 variables (Appendix A) for initial evaluation (78.9% of occupied stands classified correct and 89.7% of random correct). I eliminated five variables to address problems of colinearity: Total Trees per ha; Sapling Density; Small-sized Tree Density; Forb; and Grass Cover. For example, Small-sized Tree Density was eliminated because it was negatively correlated ($r = -0.698$) with Large-sized Trees and positively correlated with Sapling-sized Trees ($r = 0.628$). I entered 11 of the original 17 variables into a stepwise DFA, which reduced the model to four variables (Table 7).

Nest-tree area scale.— Goshawks selected nest-tree areas with higher densities of medium ($t = 3.63$, df = 33, $P = 0.001$) and large trees ($t = 2.69$, df = 51, $P = 0.010$), higher canopy closure ($t = 3.11$, df = 51, $P = 0.003$), and higher forb cover ($t = 3.14$, df = 51, $P = 0.003$) (Table 11). Sapling density in occupied nest-tree areas tended to be lower near the edge of the nest stand ($r = 0.558$, $P = 0.006$). In contrast, sapling densities in random nest-tree areas were uniform ($r = -0.144$, $P = 0.447$). Random nest-tree areas also exhibited higher sapling density ($t = -3.37$, df = 51, $P = 0.001$), higher total tree density ($t = -2.24$, df = 51, $P = 0.029$), lower total plant ground cover ($t = 3.20$, df = 9.40, $P = 0.003$), and lower mean height to the lowest live limb ($t = 2.57$, df = 51, $P = 0.013$) (Table 11). Multiple canopy layers (4 to 5) comprised 62.5% of occupied nest-tree areas

Table 11. Goshawk nest-tree area scale univariate results for continuous variables. A + or – following *P*-values 0.050 indicate the direction of observed trends. *P*-values < 0.003 represent significant differences based on Bonferroni adjustments for multiple comparisons.

	Occupied nest area (n = 23)			Random nest area (n = 30)			
Variable[a]	Mean	SE	Range	Mean	SE	Range	*P*
Mean tree height (m)	20.05	0.89	11-28	17.84	0.76	9-26	0.064
Mean live height (m)	10.16	0.54	5-15	7.92	0.64	0-15	0.013+
Total tree density (trees/ha)[bc]	1103.98	81.37	519-1729	1674.74	176.04	371-4000	0.005-
Sapling[b]	336.43	48.13	49-939	863.54	152.36	124-3878	0.001-
Small[b]	407.01	58.88	0-988	616.07	95.94	0-1655	0.404
Medium[bc]	303.92	25.96	74-543	168.78	28.20	0-667	0.001+
Large[b]	36.51	9.43	0-198	13.17	4.70	0-99	0.010+
Extra-large[b]	20.40	6.71	0-99	13.17	5.13	0-125	0.329
Basal area (m sq./ha)	42.75	1.85	26-61	34.34	2.42	10-57	0.008+
Canopy closure (%)[d]	68.83	2.50	39-90	56.86	2.76	26-82	0.003+
Total plant ground cover (%)[b]	65.77	2.95	38-90	50.94	4.58	12-98	0.009+
Shrub cover (%)	43.36	4.31	0-78	38.38	4.46	0-80	0.436
Forb cover (%)[b]	25.08	3.96	5-83	13.59	2.69	0-73	0.003+
Grass cover (%)	35.89	3.51	14-78	26.77	4.13	0-89	0.112
Wood Litter (> 2.54 cm) (%)[b]	11.09	1.50	2-30	12.27	1.62	0-33	0.821
Seedlings (0.04 ha plot)[bc]	43.39	15.21	0-272	1.96	6.60	0-173	0.217
Snags per ha (> 12.7 cm dbh)	4.08	1.55	0-26	3.39	1.86	0-44	0.261

[a]Tree density size classes: saplings = < 12.71 cm dbh, small = 12.71 to 22.85 cm dbh, medium = 22.86 to 38.10 cm dbh, large = 38.11 cm dbh to 50.80, and extra-large = > 50.80 cm dbh

[b]Values log-transformed for analysis, although untransformed means and standard errors (SE) are reported here.

[c]Equal variances not assumed.

[d]Values arcsin-transformed for analysis; untransformed means and SE are reported here.

versus only 33.3% of random areas; however, the difference was not highly significant ($P = 0.064$, Table 12).

The final DFA model clearly separated occupied from random nest-tree areas based on Canopy Closure, Plant Cover, Large Tree Density, and Sapling Density (78.3% of occupied classified correct, 80.0% of random correct) (Figs. 9 and 10, Table 7). Group centroids (occupied 0.897; random -0.688) were significantly different ($\lambda = 0.64$, $\chi^2 = 24.26$, $P < 0.001$). Between group differences explained only 39.1% (canonical correlation = 0.625) of the variation in the DFA model, and covariance matrices were heterogeneous (Box's $M = 33.89$, $P = 0.001$).

The full DFA model included 17 variables (Appendix A) for initial entry (81.8% of occupied classified correct and 86.7% of random correct). I removed six variables to eliminate problems with colinearity: Shrub, Forb, and Grass Cover, Number of Canopy Layers, Density of Medium Trees, and Total Trees/Ha. Total plant cover was allowed to represent Shrub, Forb and Grass Cover. I then entered 11 variables into a stepwise DFA, which reduced the model to four discriminating variables (Table 7).

Nest-tree scale.— Goshawks nested in Douglas-fir more than any other tree species (69.6%) (Fig. 11). Other species used for nest trees were lodgepole pine (17.4%), aspen (8.7%), and Engelmann spruce (4.4%). Tree selection was dependent on species (Fisher's exact test, $P = 0.008$). At random sites, lodgepole pine (52.0%) or Douglas-fir (48.0%) were the only two species available.

Table 12. Goshawk nest-tree area scale contingency analysis results for number of canopy layers.

Variable	Occupied nest areas ($n = 23$) Observed	Occupied nest areas ($n = 23$) Expected	Random nest areas ($n = 30$) Observed	Random nest areas ($n = 30$) Expected	P^a
Number of canopy layers					
2	0.0	2.2	5.0	2.8	
3	8.0	10.0	15.0	13.0	0.067
4	9.0	6.5	6.0	8.5	
5	6.0	4.3	4.0	5.7	

[a] P-value reported from Fisher's exact test.

Figure 9. Goshawk nest-tree area scale final model discriminant function analysis showing frequency distributions of canonical discriminant function scores for (A) occupied nest-tree areas ($n = 23$) and (B) random nest-tree areas ($n = 30$). Discriminating variables are: Total Plant Cover (%), Canopy Closure (%), Density of Large-sized Trees (trees/ha 38.11 to 50.80 cm dbh), and Density of Saplings (trees/ha < 12.71 cm dbh). Horizontal arrows indicate the direction trend for each variable. Group centroids are marked with a vertical arrow (↓).

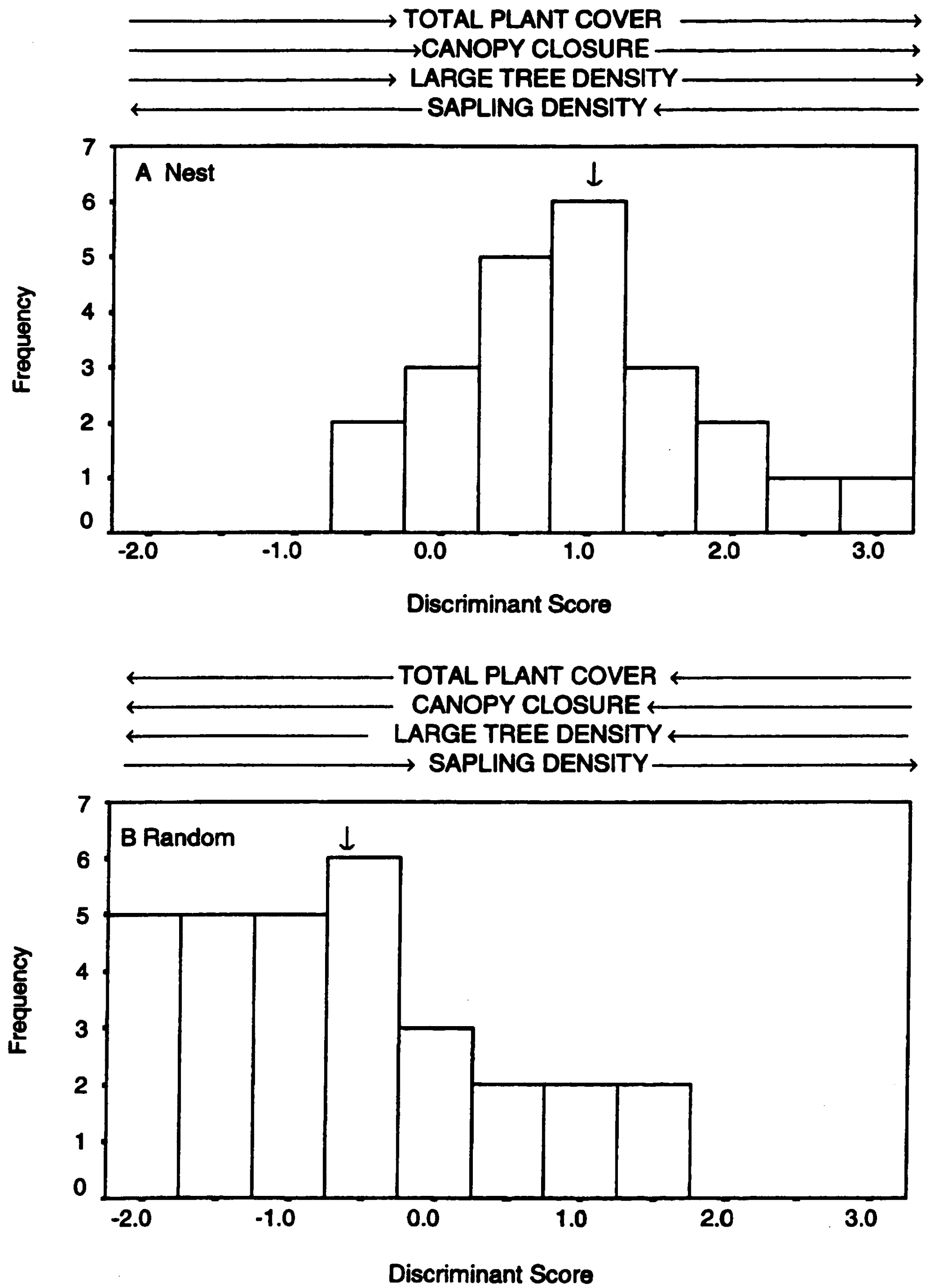


Figure 10. Goshawk nest-tree area scale final model discriminant function analysis showing probability distribution of discriminant scores. Data represent the probability that a nest-tree area is random ($n = 23$ for occupied, $n = 30$ for random). Mean probabilities are marked with a vertical arrow, and circled cases represent misclassified nest areas.

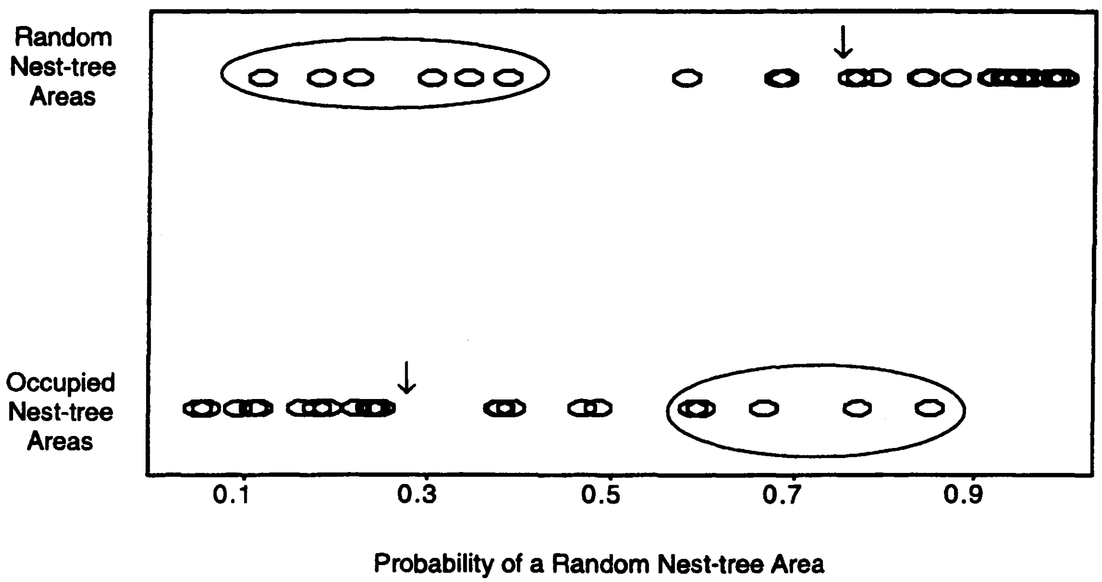
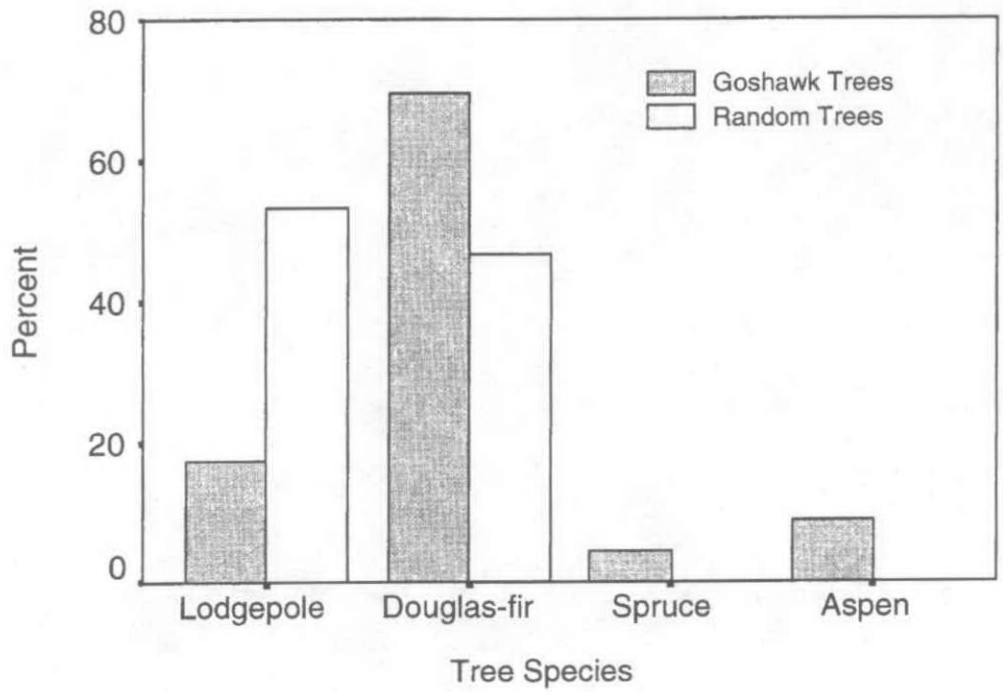


Figure 11. Bar chart of nest tree species. Data indicate the percent of goshawk nest trees (n = 23) and random trees (n = 30) comprised of each tree species.



Goshawks positioned nests 7.01 to 20.12 m high in the tree (mean = 11.81 ± 3.33 m), generally in the upper 50% (mean = 55.02 ± 11.34 m) of the tree either at the point where the lowest live limb occurred (43.5%), or from 1 to 4 m above or below the lowest live limb (57.5%). The only exception was one nest in an Engelmann spruce where the lowest live limb occurred at 2.13 m above the ground and the nest occurred at 45 m. Nests were constructed against the tree trunk on either lateral branches (13.0%) or a v-shaped split (87.0%) in the trunk that most likely resulted from damage to the apical bud during development of the tree. In all cases, nest bowls faced in a northerly direction.

In general, goshawk nest trees occupied dominant (47.8%) or codominant (53.2%) positions within the stand with crown vigor ranging from fair to moderate (60.9%) to fully vigorous (26.1%). The mean crown ratio for occupied nest trees was 48.5 ± 0.04% versus 56.0 ± 0.04% for random; however, the difference was not significant (t = -1.40, df = 51, P = 0.167). Only one of the nest trees, lodgepole pine, was infested with mountain pine beetle. This tree was dead with little remaining canopy cover (and the goshawk nest failed). The remaining occupied nest trees were alive, with no apparent mistletoe or infestations of bark beetle.

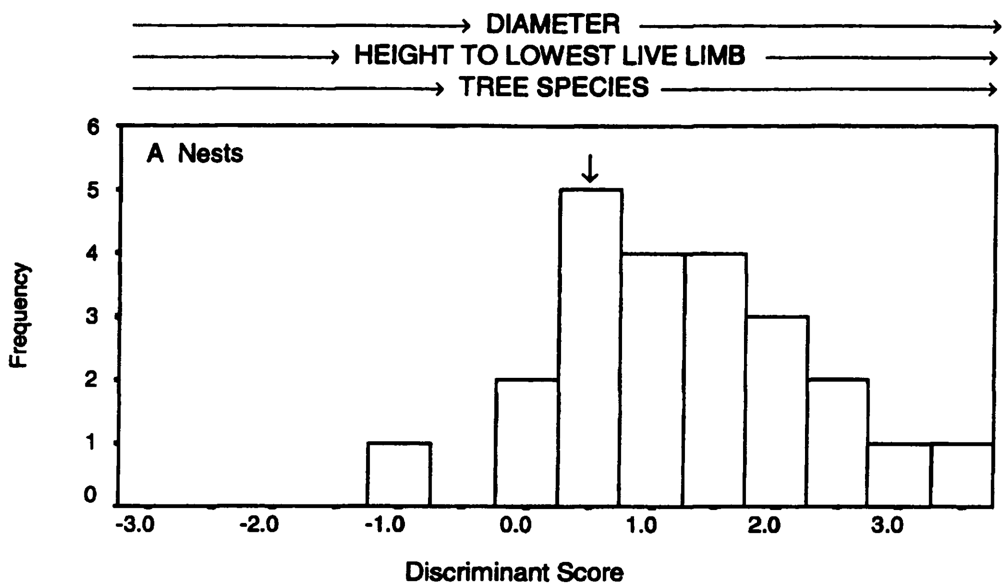
Compared with random trees, occupied nest trees were taller (t = 3.29, df = 51, P = 0.002), the lowest live limb was higher (t = 2.94, df = 51, P = 0.005), and diameter at breast height was larger (t = 4.30, df = 51, P < 0.001) (Table 13).

Variables entered into the final DFA model were: Diameter at Breast Height, Height to Lowest Live Limb, and Tree Species (87.0% of occupied classified correct and 90.0% of random correct) (Figs. 12 and 13). Group centroids (1.147 for occupied

Table 13. Goshawk nest-tree scale univariate results for continuous variables. A + or – following *P*-values 0.050 indicate the direction of observed trends. *P*-values < 0.017 represent significant differences based on Bonferroni adjustments for multiple comparisons.

	Occupied nest trees ($n = 23$)			Random trees ($n = 30$)			
Variable	Mean	SE	Range	Mean	SE	Range	*P*
Tree height (m)	21.79	1.19	13-33	17.11	0.85	7-25	0.002+
Height to lowest live limb (m)	10.93	0.89	2-20	07.55	0.74	0-16	0.005+
Diameter at breast height (cm)	37.47	2.68	20-67	22.82	2.16	10-68	<0.001+

Figure 12. Goshawk nest-tree scale final model discriminant function analysis showing frequency distributions of canonical discriminant function scores for (A) occupied nest trees ($n = 23$) and (B) random nest trees ($n = 30$). Discriminating variables are: Diameter at Breast Height (cm), Height to Lowest Live Limb (m), and Tree Species. Horizontal arrows indicate the direction of trend for each variable. Group centroids are marked with a vertical arrow (↓).



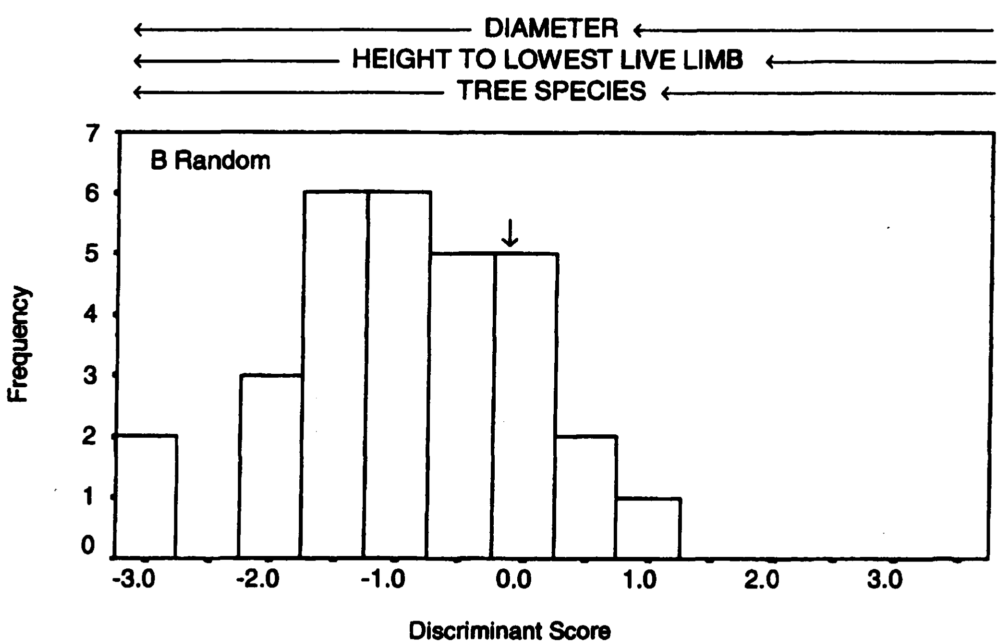
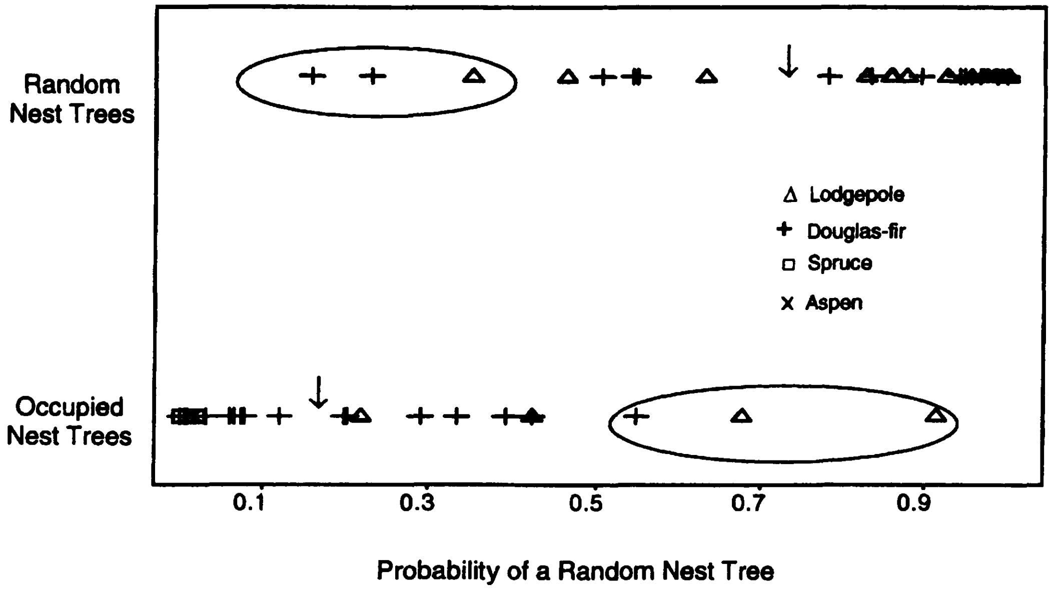


Figure 13. Goshawk nest-tree scale final discriminant function analysis showing the probability distribution of discriminant scores. Data indicate the probability that a nest tree is random ($n = 23$ for occupied nest trees, $n = 30$ for random). Mean probabilities are marked with vertical arrows, and misclassified trees are circled.



and -0.900 for random) were significantly different ($\lambda = 0.48$, $\chi^2 = 36.70$, $P < 0.001$). Between- group differences explained 52.4% of the variation in the model, and covariance matrices were heterogenous (Box's $M = 27.63$, $P < 0.001$).

The full DFA model included all four of the original variables for initial evaluation (Appendix A) and entry into a stepwise DFA. Stepwise selection eliminated Tree Height at step 4, because this variable was highly correlated ($r = 0.880$) with Height to the Lowest Live Limb (Table 7).

Goshawks selected nest trees that were larger in diameter (mean = 37.47 ± 12.87 cm dbh, $t = 5.69$, df = 22, $P < 0.001$) and taller (mean = 21.79 m ± 5.69 m, $t = 2.33$, df = 22, $P = 0.029$) than available trees within the nest-tree area (mean = 26.22 ± 6.96 cm dbh; mean = 20.05 m ± 4.28 m Tree Height). In contrast, random sites showed no significant differences between the nest tree and available trees within the nest-tree area ($t = 0.35$, df = 29, $P = 0.729$ for Tree Diameter, and $t = -1.02$, df = 29, $P = 0.318$ for Tree Height).

Goshawk productivity relative to habitat structure.— The two nests that failed, one in each year, were located in separate lodgepole pine stands comprised of small-sized trees; however, no significant correlations were found between number of young fledged and forest cover type. Examination of the classification results (that compared occupied and random nest sites at five spatial scales) revealed that the two unsuccessful nests were misclassified (or classified as random) in the nest-tree area DFA, and one of the two unsuccessful nests was misclassified in the nest-tree, nest-stand, PFA, and landscape and physiographic features analyses. Compared with the unsuccessful nests, 76.9% and

93.8% of the successful nests exhibited higher probabilities (> 0.59) of being classified correct at the nest stand and nest-tree area scales, respectively.

At the landscape scale, the number of young that fledged per nest was negatively associated with the size of the nonforested opening nearest to the nest. At the nest-stand scale, negative associations resulted for total tree density ($r = -0.541$, $P = 0.037$), sapling density ($r = -0.575$, $P = 0.025$), and small-sized tree density ($r = -0.541$, $P = 0.037$). At the nest-tree area scale, positive correlations were found between the number of young that fledged and mean tree height ($r = 0.505$, $P = 0.032$), number of canopy layers ($r = 0.495$, $P = 0.037$), basal area ($r = 0.472$, $P = 0.048$), large tree density ($r = 0.680$, $P = 0.002$), and the discriminant scores from the final DFA model ($r = 0.604$, $P = .008$). No significant correlations resulted from PFA or nest tree scale analyses.

DISCUSSION

The fundamental goal of this study was to fill a knowledge gap for the goshawk in a geographic area where the species had not been studied previously. Kean and Morrison (1994) stated that descriptive or correlative research on the goshawk is necessary to identify patterns, but they emphasized that such research should serve as a baseline for developing long-term demographic studies. With this in mind, I identified the pattern of distribution for a sample population of nesting goshawks, compared habitat use versus availability at the landscape scale, and analyzed nesting habitat selection at five hierarchical scales ranging from the landscape to the nest tree. Goshawks, like many bird species, are thought to select habitat through a hierarchical process, or a series of innate and learned behaviors that result in decisions about habitat use at different scales of the environment (Hildén 1965, Hutto 1985). To define and understand this process as it applies to forest management, I defined and measured selection at each spatial scale with techniques consistent with those used by forest managers. Finally, I assessed reproductive output among occupied habitats to gain insight into which habitats are suitable for nesting. Results should be used as a guide for future studies or applied cautiously in current management decisions.

HABITAT ANALYSIS

Goshawk nest distribution relative to landscape patterns.— Goshawks nesting in west-central Montana are clearly limited in distribution, and prefer relatively open-grown stands dominated by mature and old-growth Douglas-fir or lodgepole pine located at lower elevations on north-facing slopes. Goshawks nested in a 3 km-wide area that encompassed the interior Douglas-fir zone adjacent to the grassland/forest interface and included the lower elevations where lodgepole pine occurs (where Douglas-fir is a late seral species). Distribution was similar to that found in south-central Wyoming where goshawks appear to nest within a narrow zone of Douglas-fir and lodgepole pine adjacent to the grassland/forest interface (J. Squires pers. comm.). Conversely, in the southwestern United States, where topography is relatively gentle, goshawks nested in a clustered distribution within a more than 20-km wide area comprised of spruce-fir, mixed-conifer, and ponderosa pine adjacent to shrubsteppe plains (Reynolds et al. 1994). Results emphasize the continued need for site-specific information on nesting goshawks, because landscapes differ geographically and thus require different landscape management approaches (Hejl 1992). Results further demonstrate that, compared with the southern Rockies, habitat availability in the central and northern Rockies is more limited simply because forest cover types change more abruptly with increases in elevation.

Although we surveyed forested habitats in the interior of the study area, including parts of a remote roadless area, no goshawks responded to our alarm calls and no nests were located in these areas. The interior forest adjacent to the Douglas-fir zone is comprised, in ascending elevation, of dense, small-diameter lodgepole pine (often with subalpine-fir in the understory) followed by spruce-fir with dense understory vegetation (USFS 1995). These lodgepole pine areas had regenerated after stand replacement fires in 1910 and 1950 or after clearcut harvest treatments in the 1960s, whereas, the spruce-fir areas had been shaped more by insects, disease, and wind events (Arno 1980, Knight 1994, USFS 1995). The dense understory development found in the higher elevation areas typically supports snowshoe hares (Litvaitis et al. 1985), the goshawks's primary prey species in this study (Table 2). However, goshawks preferred to nest in more open-grown, lower-elevation areas, where habitats are drier and thought to support fewer hares. The goshawk's avoidance of subalpine-fir, spruce-fir, and the higher-elevation lodgepole in the study area supports the hypothesis that an upper density limit for tree and understory development exists, beyond which nesting goshawks do not occur (DeStefano and McCloskey 1997).

Cover types found at higher elevations are typically managed as roadless areas, and thus, are left relatively intact (USFS 1995, pers. obs.). Conversely, the elevational zone where all of my nests occurred is influenced heavily by livestock grazing, timber harvest, and a high density of roads. Nevertheless, goshawks selected nest sites within these more intensively managed areas (see below).

PFA analysis – implications for selection of a core area of mature forest within an intensively managed landscape. Results clearly showed that goshawks nesting in the northern Flints selected a core area of mature forest that was surrounded by dense smaller-sized trees. In the 170-ha area around my nests, or PFA, only 11.3 ± 5.1% (19.2 ± 8.7 ha) contained mature or old growth forest (Table 8), and this area corresponded strongly to the nest stand, which was 15.4 ± 3.6 ha in size. The stand-level analysis further revealed that nesting goshawks preferred mature stands and avoided the available (or random unoccupied) stands of dense, smaller-sized trees (Table 9, Fig. 7). Results support the theory that nesting goshawks throughout the western United States consistently select for, and therefore need, mature forest (e.g. Moore and Henny 1983, Reynolds et al. 1983, Crocker-Bedford and Chaney 1988, Hayward and Escano 1989, Austin 1993, Bull and Hohmann 1994, Woodbridge and Detrich 1994, Reynolds et al. 1994, Siders and Kennedy 1996, Squires and Ruggiero 1996, Desimone 1997, Patla 1997, Daw et al 1998).

I compared the proportion of mature forest found in my PFAs with that found within a 170-ha circle around 15 nests, occupied in 1994, in Oregon (Desimone 1997) and around 27 nests, occupied at least once from 1989 to 1993, in Idaho (Patla 1997).

PFAs in Oregon and Idaho contained a much higher proportion of mature forest, from 45 to 66%, than in my PFAs, which had only 11% mature forest. Although Patla and Desimone reported that their results may have been biased because of inconsistent survey methods, they presented evidence suggesting that goshawk occupancy declined in areas where mature forest had been reduced from harvest.

In Idaho, Patla (1997) further assessed the amount of mature forest cover within various-sized areas delineated around nests that were located in some large areas of relatively undisturbed habitats. She found no difference in the amount of mature forest up to 2,400 ha. Similarly, in the southwestern United States, goshawks did not select core areas of mature forest (R. Reynolds, pers. comm.), and habitats in the southwest had not been as extensively altered by early harvest practices compared with habitats in many parts of the northern Rockies (Reynolds et al. 1994). Conversely, Desimone's (1997) and my study were done in some extensively managed habitats. In Oregon, Desimone (1997) calculated the amount of mature forest cover in various-sized circles up to 170 ha centered on nests. He found that nesting goshawks selected a core area of mature forest that was 52 ha in size surrounded by denser, smaller trees. Goshawks in the northern Flints also selected a core area of mature forest, but the area was considerably smaller than in Oregon, 19 ha. Results suggest that goshawks need mature forest for nesting; however the amount of mature forest needed remains largely unknown and may vary depending on the landscape, disturbance history, and degree of habitat fragmentation.

The concept of core nesting areas in managed landscapes has been studied for other species such as the Mexican Spotted Owl (*Strix occidentalis lucida*), a mature and old-growth associate listed as a federally threatened species in 1993 (Grubb et al. 1997). Grubb et al. (1997) found that, compared with random sites, occupied sites contained a larger proportion of forest with high canopy closure ($n = 47$) up to a 201-ha area. They determined that owls consistently selected a core area of dense canopy closure that was highest in a 2.8-ha area around nests and argued that the scarcity of high canopy areas emphasizes their importance to the owl.

In the northern Flints, 36.9% of the area surveyed contained mature and old-growth Douglas-fir and lodgepole pine. Why, then, did goshawks select such small core areas of mature forest (11.3% of the PFA)? Lower-elevation areas, where all of my goshawks nested, were influenced by extensive clearcut harvests during the 1960s followed by numerous harvests during the 1980s and 1990s. The patch size and connectivity of mature and old-growth has been reduced significantly, and fragments of mature forest now exist within a matrix of commercial thin, shelter-wood, and clearcut harvest areas (USFS 1995, 1996, 1997, 1998).

Since the abundance of other bird species have been shown to decline in forests that have been fragmented by harvest (e.g. Schmiecelow et al. 1977), one might predict that higher densities of nesting goshawks occur in less fragmented landscapes that contain larger amounts of mature forest than found in this study. However, accurate calculations for nest density are difficult to obtain, because responses of goshawks to survey methods and occupancy rates vary widely (e.g. Kennedy and Stahlecker 1993, Woodbridge and Detrich 1994, Desimone 1997, my study). Furthermore, survey techniques and methods for calculating nest density vary widely among studies, making comparison difficult (e.g.

Reynolds 1983, Reynolds et al. 1994, DeStefano et al. 1994, Desimone 1997, Patla 1997). In this study, nest density was 0.46 for every 1,000 ha surveyed randomly, somewhat lower than that found in extensively managed landscapes in other parts of the western United States, e.g. 0.70/1,000 ha surveyed in eastern Oregon (DeStefano et al. 1994), and 0.58 to 1.07/1,000 ha in northern California (Woodbridge and Detrich 1994). From the above results, one might conclude that nest density among managed landscapes varies and may depend on management intensity, geographic location, or a combination of both factors.

However, in less-disturbed habitats in Idaho, Patla (1997) reported a nest density of 0.33/1000 ha of mature Douglas-fir and lodgepole pine forest available in the study area, substantially lower than in my study, 0.93/1,000 ha (calculated by dividing the 13 nests occupied in 1998 by 14,009 ha of mature Douglas-fir and lodgepole pine available in the study area (Table 1), suggesting that nest density in managed landscapes is higher than in unmanaged landscapes. However, Patla reported 0.24 nests per 1,000 ha for the entire study area, which was similar to that found in this study, 0.29/1,000 ha (13 nests/45,528 ha; Table 1), suggesting that nest density does not differ between extensively managed and relatively undisturbed habitats. Patla (1997) noted that estimates of nest density in Idaho may be inaccurate from inconsistent survey techniques. Furthermore, nest density per area surveyed could not be determined and therefore is not comparable with this study.

Studies in other parts of North America have suggested that some goshawk prey species, such as scuirids, are more abundant in mature or old-growth forests (e.g. Carey

1995). On the other hand, a variety of forest successional stages is needed to support such prey as snowshoe hares (abundant in seedling/sapling thickets; Litvaitis et al. 1985), Columbian ground squirrels (associated with meadows and forest edge; Thomas et al. 1988), and Blue Grouse (common in open conifer forest; Johnsgard 1986). Obviously, goshawks need some amount of mature forest, the amount of which remains largely unknown.

Landscape spatial patterns, physiographic features, and habitat structure relative to nest-site selection and productivity.— Goshawks clearly selected nest sites in association with north aspects, the edges of nest stands, and small forest openings. Nest-site selection was dependent on aspect, with 86.4% of occupied nest sites occurring on north-facing slopes (Table 6, Fig. 4). Furthermore, goshawks selected large areas surrounding the nest, or PFAs, that were comprised of predominantly north aspects (Table 8, Figs. 6). Some studies have reported that goshawks prefer north aspects (Moore and Henny 1983, Hall 1984, Hayward and Escano 1989), and others found no preference for aspect (Crocker-Bedford and Chaney 1988, Kennedy 1988, Squires and Ruggiero 1996). Reynolds et al. (1992) suggested that goshawks select microsites on north aspects that support dense vegetation and cooler temperatures. In drier habitats of west-central Montana (Habeck 1987), north aspects contain cooler, shaded environments that promote lush development of shrubs and trees and provide good habitat for snowshoe hare (Wolf et al. 1982) and grouse sp. (Stauffer and Peterson 1985) prey (Table 2), and high canopy closure; all of which are preferred habitat components of nesting goshawks.

In the northern Flints, goshawks were strongly associated with one edge of the nest stand and small forest openings near the nest. The preference for one side of the stand could not be analyzed adequately in the absence of a cluster analysis that could account for all stands or patches of forest adjacent to the nest stand. Measurements taken from the nest to nearest landscape features or covertypes indicated that, on average, goshawks selected nests near open-grown Douglas-fir and avoided dense small-diameter lodgepole pine, regenerating clearcuts, and large forest openings. Results demonstrated that within a much larger area, the PFA, nesting goshawks preferred sites with fewer clearcut harvest units (Fig. 6), selected nest sites near small forest openings (Fig. 4, Table 5), and avoided nesting in or near dense small diameter forest (Table 9, Fig. 7). Nesting productivity was inversely related to the size of forest openings near the nest and to the density of small-diameter trees in nest stands, suggesting that such habitats are of low quality to goshawks. Large openings are thought to increase competition from open-forest raptors (Crocker-Bedford 1990), which seen frequently during the duration of this study. Conversely, high densities of small-diameter trees decrease the suitability of nesting habitat (this study) and the availability of prey species to goshawks (e.g. Beier and Drennan 1997). Overall, results are inconclusive because of the small sample size, short study duration, and large number of factors thought to affect productivity in nesting raptors (Newton 1979).

Nest-stand and nest-tree area structure relative to studies in the Northern and Central Rockies.— In the northern Flints, results suggest that nesting goshawks prefer mature to old-growth Douglas-fir or lodepole pine stands that are open grown, high in canopy closure and plant ground cover, and contain forest floors that are relatively clear of saplings and wood litter (Table 9). The pattern of goshawks consistently "selecting nest sites with abundant large trees and high canopy closure" has occurred in studies throughout North America and Europe (summarized in Daw et al. 1998). In the northern and central Rockies, only four studies have assessed goshawk nest-site characteristics. In southern Wyoming, goshawks nesting in lodgepole pine similarly preferred stands composed of large, mature trees, few small-diameter trees, and low wood litter. Canopy closures in the northern and central Rockies were consistently high, 65 ± 3% in Wyoming (Squires and Ruggiero 1996), 77 ± 7% in southern Idaho (Patla 1997), 80 ± 3% in central Montana (Hayward and Escano 1989), 72 ± 3% in central Montana (Whitford 1991), and 69 ± 5% in my study.

Total tree densities in nest areas in northern Idaho and western Montana (Hayward and Escano 1989), southern Wyoming (Squires and Ruggiero 1996), and southern Idaho (Patla 1997) were well within the mean and confidence limits found in my study (1,138 ± 338 trees/ha). Total tree densities in southern Wyoming and my study differed from random stands, suggesting that goshawks prefer stands that are less dense than available habitats. However, goshawks nesting in Douglas-fir in central Montana (Whitford 1991) nested in stands with tree densities that were significantly lower, 475 ± 2.5 trees/ha, than all other areas of the northern Rockies.

Nest-tree scale.— Reynolds et al. (1992) stated that the goshawk's selection of a nest tree is secondary to selection of a nest stand, that is, once a goshawk selects a suitable nest stand, many trees will be available for nesting. In my study, Douglas-fir trees were selected most frequently, even when the dominant overstory tree species was lodgepole pine. Furthermore, results suggested that goshawks preferred trees that were larger in diameter and taller than available trees in the nest area. Results of studies done elsewhere have also suggested that goshawks select the largest available trees for nesting (e.g. Hall 1984, Squires and Ruggiero 1996).

Current management practices in goshawk habitat.— I compared the total tree densities that result from current forestry practices in my study area and found that managed Douglas-fir stands tend to have tree densities that are well below those used by goshawks. The typical silvicultural treatment in Douglas-fir or Douglas-fir/lodgepole mixed stands calls for removal of all lodgepole pine, followed by commercially thinning the Douglas-fir to 98.8 to 247.0 trees per ha, considerably lower than in my goshawk stands, 1,503 ± 373 trees per ha.

In contrast, stands dominated by lodgpole pine are treated with regeneration harvests that remove nearly all of the trees or with post-and-pole thinning that results in tree densities that are well within the range of goshawk nest stands. Post-and-pole thinning tends to remove all of the smaller trees (< 15 cm in diameter), resulting in total tree densities of 1,394 trees per ha (spaced 9' x 9'). However, the resulting stands are often uniform in structure, do not allow for regeneration of shrubs or saplings in the understory, and overall, lack the variation in vertical structure found in my goshawk nest stands (B. Schuelke, pers. comm.). In the future, silvicultural prescriptions in potential goshawk nest stands could be adjusted to meet goshawk nesting preferences while satisfying timber harvest needs.

Graham et al. (1997) stated that fire may be the primary disturbance factor that provided and maintained goshawk prey populations in western landscapes (Graham et al. 1997). In the northern Flints, and much of the northern Rockies, analysis of fire scars that nonlethal fires occurred in Douglas-fir stands occupied by goshawks at 15- to 50-year intervals, burned in a mosaic clearing patches of lower ground fuels, such as seedling/sapling thickets, and occasionally torched individual or groups of overstory trees (Arno 1980, 1995). Conversely, lodgepole pine stands occupied by goshawks typically developed through stand-replacement events every 150 to 250 years. Evidence from this study suggests that dense sapling and small-sized trees render stands unsuitable for nesting goshawks. Although a certain degree of understory development is necessary to provide cover for prey species, (such as snowshoe hares and grouse) there are tree density limits wherein prey (such as snowshoe hares and red squirrels) can become unavailable to goshawks. Prolonged lack of disturbance may reduce the suitability of habitat for prey.

Currently, the goshawk is considered sensitive in all USFS regions and has been a U.S. Fish and Wildlife Service (USFWS) species of concern for possible listing as threatened or endangered status since 1992 (Fed. Reg. 1992). In Region 1, goshawks are considered old-growth Douglas-fir associates (Warren 1990) and have been identified as a Management Indicator Species for old-growth Douglas-fir on 10 national forests. Concern for goshawks in Region 1 has resulted in numerous requests under the Freedom of Information Act, timber-sale appeals, and lawsuits. In 1996, Region 1 conducted an assessment of goshawk management with the goal of synthesizing information, identifying known risks, and determining if management changes were warranted (Maj 1996).

Results indicated that each national forest varies in its approach to management of goshawk habitat. Many national forests believe they meet goshawk needs through the management of old-growth or riparian habitat. The majority of forests, with some modification, use the Northern Region Goshawk Habitat Suitability Model (Warren 1990), which emphasizes mature Douglas-fir forest types, to assess potential nesting habitat during project analyses. Region 1 recommends that forests continue to adjust the model based on new information and research on nest-site selection, but such information is not available. Some forests, using management recommendations for the goshawk in the southwestern United States (Reynolds et al. 1992), apply concepts related to nesting areas, such as the placement of 8- to 12-ha buffers around active nests. However, protecting occupied nest sites alone could result in adverse effects to breeding pairs by fragmenting their territories. Accordingly, some biologists and silviculturists are developing prescriptions across landscapes to restore vegetative systems to resemble historic forest structure prior to fire exclusion. With little monitoring and follow-up, however, it is unknown how these prescriptions will affect goshawks.

In the absence of long-term monitoring data, a more conservative approach to allowing harvest activities near active nest stands should be taken to ensure that goshawk distribution is not greatly altered. This is especially important because we now know that nesting habitat is limited within western Montana landscapes.

PRODUCTIVITY, NESTING SUCCESS, AND DIET

Average number of young fledged per nest.— Nesting productivity for goshawks in the northern Flints (2.6 fledglings per nest) was slightly higher than that reported for recent studies elsewhere; i.e. 0.7 to 2.2 in the Pacific Northwest (DeStefano et al. 1994, Woodbridge and Detrich 1994,), 1.8 to 2.0 in the southern Rockies (Boal and Mannan 1994, Reynolds et al. 1994), and 1.96 in the central Rockies 1.96 (Patla 1997), but it falls within the ranges reported in earlier studies conducted throughout North American and Europe (summarized in Reynolds and Wight 1978).

In this study, goshawk productivity differed between years, which coincides with results reported from studies in other parts of western North America and Europe (e.g. Kostrzewa and Kostrzewa 1991, DeStefano et al. 1994, Patla 1997). These studies demonstrated a correlation with reduced goshawk productivity and cold, wet spring weather. Similar findings have been reported for other raptor species such as the European Kestrel (*Falco tinnunculus*; Kostrzewa and Kostrzewa 1991), the European Sparrowhawk (Newton 1991), and for a number of migratory and resident songbird species (Hejl and Beedy 1986, Hejl and Balda 1988).

Nesting success.— Researchers typically estimate nesting success for goshawks by calculating the proportion of the total number of nests that was successful (raw nest success) and recognize that this method may overestimate actual nesting success (i.e. Woodbridge and Detrich 1994). Overestimates may result from nest failures that occur early in that nesting period and are undetected.

I used the Mayfield method (1975) to account for some of the variation, because this method considers the number of days a nest is under observation and provides a more accurate estimate for the sample of nests. Because Mayfield nesting success has not been reported for goshawks, the estimate from my study is not comparable to studies done elsewhere, but can serve as a basis for future comparisons. The proportion of the total number of successful nests (raw nesting success) observed in my study, 83% in 1997 and 92% in 1998, falls within the ranges reported in most North American and European studies (Reynolds and Wight 1978, Boal and Mannan 1994, Destefano et al. 1994, Reynolds et al. 1994, Woodbridge and Detrich 1994). Mayfield nesting success was considerably lower than the raw nesting success reported for this and all other studies, 67.9% for 1997 and 1998 combined.

The two nest failures, one in each year, likely occurred during cold spring storms early in the nestling period, although the exact cause of failure could not be determined. Because the adults were not present when I discovered the nest failures (4 to 7 days after the last nest check), I cannot rule out adult mortality or nest abandonment. In the southern Cascades, Woodbridge and Detrich (1994) found that severe spring weather caused 18% of nest failures and Great Horned Owl predation 18%. Boal and Mannan (1994) reported 45% from owl predation and 18% from nestlings falling out of the nest.

Nesting chronology.— Nesting chronology for this study was within the range of dates reported for western North American (e.g. Reynolds et al. 1994, Patla 1997). In my study, annual variation in the mean onset of egglaying (i.e. 10 days earlier in 1998 than in

1997) was associated with the drier, warmer weather that occurred during April 1998 compared with 1997.

Goshawk Diet.— Goshawks prey opportunistically on a variety of mammalian and bird species with differing ecological requirements (e.g. Reynolds et al. 1992, Doyle and Smith 1994). In the northern Flints, 81.0% of the prey biomass consisted of mammals, with snowshoe hares and red squirrels the most important prey species. In 1997, prey at three of six nests consisted almost entirely of snowshoe hares. In 1998, snowshoe hares were not as abundant in the diet and were not observed as frequently during goshawk surveys (27 snowshoe hare sightings in 1997 versus only 6 sightings in 1998), and goshawks appeared to increase their consumption of red squirrels in 1998 (Table 2).

Similarly, hares were the most important prey item in southern Idaho (Patla 1997) and in the boreal forests of Canada (Doyle and Smith 1994), where snowshoe hare numbers rise and fall dramatically over a 10-year period (Keith 1963). Results of Doyle and Smith (1994) suggested that goshawk populations in Canada respond demographically to the "10-year hare cycle." In west-central Montana, where habitats are drier and more fragmented, little is known about hare populations. In fact, research on snowshoe hares in the Rockies is limited to two studies, one in northwestern Montana (Adams 1959), and one in Colorado and Utah (Dolbeer and Clark 1975).

SUMMARY OF CONCLUSIONS

Nesting goshawks are limited in distribution by habitat availability, dependent on mature and old-growth cover types in the Douglas-fir zone, and select for specific landscape and habitat structural features ranging from the landscape level to the nest tree. In fragmented landscapes, goshawks select a core area of mature forest surrounded by dense, smaller-sized trees. Reproductive success and nesting productivity was higher when nest sites were situated near smaller nonforested openings, in nest stands that contained lower sapling densities, and in nest-tree areas with a higher density of large-sized trees.

Timber harvest and fire suppression can reduce the overall suitability of nesting habitat. Conversely, well-designed management treatments should be able to improve existing conditions for goshawks through landscape management of nesting habitat and habitat for primary prey populations (snowshoe hares, red squirrels, Blue Grouse, and Columbian ground squirrels).

MANAGEMENT RECOMMENDATIONS

1. Managers need to recognize sample size as a limitation in a two-year study and the potential consequences that can result from finding a low number of occupied nests. Designing management plans for a species considered sensitive to forest management, such as the goshawk, requires the power to detect differences because the outcome of inaccurate decisions can be detrimental.

2. Long-term monitoring of known goshawk populations in this Region is needed to determine the demographic responses of goshawks to forest management practices (i.e. reductions in mature forest and increases in open-forested habitat from harvest, and increases in sapling densities from absence of fire).
3. Because information on prey populations are limited, current studies of hare and other prey species are needed in drier habitat types of western Montana.
4. Telemetry studies of goshawk fledglings in this region are needed to adequately define the size, habitat composition, and the allowable management intensity within the PFA.
5. Harvest in Douglas-fir and lodgepole pine forest covertypes should be adjusted to meet management needs while simultaneously meeting the needs of nesting goshawks.
6. Consistent management guidelines are needed in this Region to adequately protect nesting habitat.
7. There is a need for managers to survey for goshawks during the peak calling period when the probability of detection is highest. I identified a peak calling period for this region, 1 June to 10 July.
8. To manage for viable populations of goshawks across the Region, we need to: (1) define regional breeding (and wintering) habitat at multiple spatial scales similar to those defined in this study; and (2) evaluate temporal and spatial changes in preferred goshawk habitat as a result of changing land-use patterns.

LITERATURE CITED

Adams, S.L. 1959. Analysis of populations of snowshoe hares in northwestern Montana. Ecological Monographs 29:141-170.

Arno, S.F. 1980. Forest fire history in the northern Rockies. Journal of Forestry 78:460-465.

_____. 1995. Age-class structure of old growth ponderosa pine/Douglas-fir stands and its relationship to fire history. USDA For Ser. Research Paper, INT-RP-481, Intermountain Research Station, Ogden, UT.

Austin, D. 1993. Habitat use and home range size of breeding Northern Goshawks in the southern Cascades. Master's thesis, Oregon State University. Corvallis, OR.

Beier, P., and J.E. Drennan. 1997. Forest structure and prey abundance in foraging areas of Northern Goshawks. Ecol. Appl. 7:564-571.

Boal, C.W. 1994. A photographic and behavioral guide to aging nestling Northern Goshawks. Stud. Avian Biol. 16:32-40.

______, and R.W. Mannan. 1994. Northern Goshawk diets in ponderosa pine forests on the Kaibab Plateau. Stud. Avian Biol. 16:97-102.

Bonham , C.D. 1989. Measurements for terrestrial vegetation. John Wiley and Sons, New York, NY.

Bosakowski, T., and R. Speiser. 1994. Macrohabitat selection by nesting Northern Goshawks: implications for managing eastern forests. Stud. Avian Biol. 16:46-49.

Bright-Smith, D.J., and R.W. Mannan. 1994. Habitat use by breeding male Northern Goshawks in northern Arizona. Stud. Avian Biol. 16:58-65.

Bull, E.L., and J.E. Hohmann. 1994. Breeding biology of Northern Goshawks in northeastern Oregon. Stud. Avian Biol. 16:97-105.

Byers, C.R., R.K. Steinhorst, and P.R. Krausman. 1984. Clarification of a technique for analysis of utilization-availability data. J. Wildl. Manage. 48:1050-1053.

Carey, A.B. 1995. Sciurids in Pacific Northwest managed forests. Ecological Applications 5:648-661.

Cody, M.L. (ed.) 1985. Habitat selection by birds. Academic Press. Orlando, FL.

Crocker-Bedford, D.C. 1990. Goshawk reproduction and forest management. Wildl. Soc. Bull. 18:262-269.

______, and B. Chaney. 1988. Characteristics of goshawk nesting stands. Pages 210-217 in, R.L. Glinski, et al. (Eds.). Proceedings of the southwest raptor management symposium and workshop. Natl. Wildl. Fed. Sci. Tech. Ser. No. 11.

Daubenmire, R.F. 1959. A canopy-coverage method of vegetation analysis. Northwest Sci. 33: 43-46.

Daw, S.K., S. DeStefano, and R.J. Steidl. 1998. Does search method bias the description of Northern Goshawk nest-site structure? J. Wildl. Manage. 62:1378-1383.

DeSimone, S.M. 1997. Occupancy rates and habitat relationships of Northern Goshawks in historic nesting areas in Oregon. Master's thesis, Oregon State University, Corvallis, OR.

DeStefano, S., and J. McCloskey. 1997. Does forest structure limit the distribution of Northern Goshawks in the Oregon Coast Ranges? J. Raptor Res. 31:34-39..

______, B. Woodbridge, and P.J. Detrich. 1994. Survival of Northern Goshawks in the southern Cascades of California. Stud. Avian. Biol. 16:133-136.

Dolbeer, R.A., and W.R. Clark. 1975. Population ecology of snowshoe hares in the central Rocky Mountains. J. Wildl. Manage. 39:535-549.

Doyle, F.I., and J.M.N. Smith. 1994. Population responses of Northern Goshawks to the 10-year cycle in numbers of snowshoe hares. Stud. Avian Biol. 16:1333-136.

Dunning, J.B. 1984. Body weights of 686 species of North American birds. Western Bird Banding Association, Monograph No. 1.

Graham, R.T., T.B. Jain, R.T. Reynolds, and D.A. Boyce. 1997. The role of fire in sustaining Northern Goshawk habitat in Rocky Mountain forests. Proceedings: fire effects on rare and endangered species and habitat conference. 13-16 Nov. 1995, Couer'd Alene, ID.

Grubb, T.G., J.L. Ganey, and S.R. Masek. 1997. Canopy closure around nests of Mexican Spotted Owls in northcentral Arizona. J. Wildl. Manage. 6:334-342.

Habeck, J.R. 1987. Present day vegetation in the northern Rocky Mountains. Annals Missouri Botanical Garden. 74:804-840.

Habeck, J.R. 1990. Old growth ponderosa pine-western larch forests in western Montana: ecology and management. Northwest Environmental Journal 6:271-292.

Hall, P.A. 1984. Characteristics of nesting habitat of goshawks in northwestern California. Master's thesis, Humbolt State University, Arcata, CA.

Hargis, C.D., C. McCarthy, and R.D. Perloff. 1994. Home ranges and habitats of Northern Goshawks in eastern California. Stud. Avian Biol. 16:66-74.

Hayward, G.D., and R.E. Escano. 1989. Goshawk nest-site characteristics in western Montana and northern Idaho. Condor 91:476-479.

Hejl, S.J., and E.C. Beedy. 1986. Weather-induced variation in the abundance of birds. In Wildlife 2000: modeling habitat relationships of terrestrial vertebrates. Edited by J. Verner, M.L. Morrison, and C.J. Ralph. The University of Wisconsin Press, Madison, WI.

______, J. Verner, and R.P. Balda. 1988. Weather and bird populations in true fir forests of the Sierra Nevada, California. Condor 90:561-574.

______. 1992. The importance of landscape patterns to bird diversity: a perspective from the northern Rocky Mountains. The Northwest Env. J. 8:119-137.

Hildén, O. 1965. Habitat selection in birds. Ann. Zool. Fennici 2:53-75.

Huberty, C.J. 1994. Applied discriminant analysis. John Wiley and Sons, New York, NY.

Hunter, M.L. Jr. 1991. Coping with Ignorance: the course filter strategy for maintaining biodiversity. Pages 266-281 in K.A. Kohn [Ed.]. Balancing on the brink of extinction. Island Press, Covelo, CA.

Hutto, R.L. 1985. Habitat selection by nonbreeding, migratory land birds. Pages 455-476 in, Cody, M.L. (Ed.). Habitat selection by birds. Academic Press, Orlando, FL.

_____. 1995. Using landbirds as an indicator species group. Draft report. Division of Biological Sciences, University of Montana, Missoula, MT.

Johannson, C., P.J. Hardin, and C.M. White. 1994. Large-area Goshawk habitat modeling in Dixie National Forest using vegetation and elevation data. Stud. Avian Biol. 16: 50-57.

Johnsgard, P.A. 1990. Hawks, eagles, and falcons of North America. Smithsonian Institution Press, Washington, D.C.

______. 1986. Birds of the Rocky Mountains: with particular reference to national parks in the Northen Rocky Region. Colorado Associated University Press, Boulder, CO.

Joy, S.M., R.T. Reynolds, and D.G. Leslie. 1994. Northern Goshawk broadcast surveys: hawk response variables and survey costs. Stud. Avian Biol. 16:24-30.

Keane, J.J., and M.L. Morrison. 1994. Northern Goshawk ecology: effects of scale and levels of biological organization. Stud. Avian Biol. 16: 3-11.

Keller, M.E., and S.H. Anderson. 1992. Avian use of habitat configurations created by forest cutting in southeastern Wyoming. Condor 94:55-65.

Kennedy, P.L. 1988. Habitat characteristics of Cooper's Hawks and Northern Goshawks nesting in New Mexico. Pages 210-217 in, R.L. Glinski, et al. (Eds.). Proceedings of the southwest raptor management symposium and workshop. Natl. Wildl. Fed. Sci. Tech. Ser. No. 11.

______. 1997. The Northern Goshawk: is there evidence of a population decline? J. Raptor Res. 31:95-106.

______, and D.W. Stahlecker. 1993. Responsiveness of nesting Northern Goshawks to taped broadcasts of 3 conspecific calls. J. Wildl. Manage. 57:249-257.

______, J.M. Ward, G.A. Rinker, and J.A. Gessaman. 1994. Post fledgling family areas in Northern Goshawk home ranges. Stud. Avian Biol. 16:75-82.

Knight, D.H. 1994. Dynamics of subalpine-fir forests. Pages 128-138 in, G.D. Hayward and J. Verner (Eds.). Flammulated, Boreal, and Great Gray Owls in the United States: a technical conservation assessment. USDA For. Serv. Gen. Tech. Rep. RM-253, Fort Collins, CO.

Kostrezewa, A., and R. Kostrezewa. 1991. The relationship of spring and summer weather with density and breeding performance of the Buzzard *Buteo buteo*, Goshawk *Accipiter gentilis* and Kestrel *Falco tinnunculus*. Ibis 132:550-559.

Lehman, R. N., L.B. Carpenter, K. Steenhof, and M.N. Kochert. 1997. Assessing relative abundance and reproductive success of shrubsteppe raptors. J. Field Ornithol. 69:244-256.

Lilieholm, R.J., W.B. Kessler, and K. Merrill. 1993. Stand density index applied to timber and goshawk habitat objectives in Douglas-fir. Environmental Management 17:773-779.

Litvaitis, J.A., J.A. Sherbourne, and J.A. Bissonette. 1985. Influence of understory characteristics on snowshoe hare habitat use and density. J. Wildl. Manage. 49:866-873.

Losensky B.J. 1993. Historical vegetation in Region 1 by climatic sections in ecosystem classification of the northern Rocky Mountains and Great Plains. Draft report. USDA For. Ser., Missoula, MT.

Maj, M. 1996. Northern Goshawk (*Accipiter gentilis atricapillus*): assessment of monitoring and management in the Northern Region. USDA For. Serv. Region 1, Missoula, MT.

Manly, B., L. McDonald, and D. Thomas. 1993. Resource selection by animals. Chapman and Hall, London.

Mayfield, H.F. 1975. Suggestions for calculating nest success. Wilson Bull. 87: 456-466.

Moore, K.R., and C.J. Henny. 1983. Nest site characteristics of three coexisting accipiter hawks in northeastern Oregon. J. Raptor Res. 17:65-76.

Neu, C.W., C.R. Byers, and J.M. Peek. 1974. A technique for analysis of utilization-availability data. J. Wildl. Manage. 38:541-545.

Newton, I. 1979. Population ecology of raptors. Buteo Books, Vermillion, SD.

_____. 1991. Habitat variation and population regulation in sparrowhawks. Ibis 133 Suppl. I:76-88.

Niemi, G.J., and J.M. Hanowski. 1997. Raptor responses to forest management: a holarctic perspective. J. Raptor Res. 31:93-94.

Norusis, M.J. 1994. Professional statistics. SPSS, Inc. Chicago, IL.

Patla, S. 1997. Nesting ecology and habitat of the Northern Goshawk in undisturbed and timber harvest areas on the Targhee National Forest, Greater Yellowstone Ecosystem. Master's thesis. Idaho State University, Pocatello, ID.

Reynolds, R.T. 1983. Management of western coniferous forest habitat for nesting accipiter hawks. USDA For. Serv. Gen. Tech. Rep. RM-102.

______, R.T. Graham, M.H. Reiser, R.L. Bassett, P.L. Kennedy, D.A. Boyce, Jr., G. Goodwin, R.S. Smith, and E.L. Fisher. 1992. Management recommendations for the northern goshawk in the southwestern United States. USDA For. Serv. Gen. Tech. Rep. RM-217. Rocky Mountain Forest and Range Experiment Station. Ft. Collins, CO.

______, S.M. Joy, and D.M. Leslie. 1994. Nesting productivity, fidelity, and spacing of Norhtenr Goshawks in Arizona. Stud. Avian Biol. 16:106-113.

______, E.C. Meslow, and H.M. Wight. 1982. Nesting habitat of coexisting accipiters in Oregon. J. Wildl. Manage. 46:124-138.

______, and H.M. Wight. 1978. Distribution, density, and productivity of accipiter hawks breeding in Oregon. Wilson Bull. 90:182-196.

Schmiegelow, F.K.A., C.S. Machtans, and S.J. Hannon. 1997. Are boreal birds resilient to forest fragmentation?: an experimental study of short-term community responses. Ecology 78:1914-1932.

Siders, M.S., and P.L. Kennedy. 1996. Forest structural characteristics of accipiter nesting habitat: is there an allometric relationship? Condor 98:123-132.

Smallwood, K.S. 1998. Commentary on the evidence needed for listing Northern Goshawks (*Accipiter gentilis*) under the Endangered Species Act: a reply to Kennedy (D.E. Varland Ed.). J. Raptor Res. 32:323-329.

Smith, D.M., B.C. Larson, M.J. Kelty, and P.M.S. Ashton. 1997. The practice of silviculture: applied forest ecology, 9th ed. John Wiley and Sons, New York, NY.

Sokal, R.R., and F.J. Rohlf. 1995. Biometry: the principles and practice of statistics in biological research, 3d ed. W.H. Freeman and Company, New York, NY.

Speiser, R., and T. Bosakowski. 1987. Nest site selection by Northern Goshawks in northern New Jersey and southeastern New York. Condor. 89:387-394.

Squires, J.R., and J.T. Reynolds. 1997. Northern goshawk (*Accipiter gentilis*). In A. Poole and F. Gill (Eds.). The Birds of North America, No 298. The Academy of Natural Sciences, Philadelphia, Pennsylvania and The American ornithologists' Union. Washington, D.C.

______, and L.F. Ruggiero. 1996. Nest-site preference of Northern Goshawks in southcentral Wyoming. J. Wildl. Manage. 60:170-177.

Stauffer, D.F. and S.R. Peterson. 1985. Ruffed and Blue Grouse habitat use in southeastern Idaho. J. Wildl. Manage. 49:459-466.

Steidl, R.J., J.P. Hayes, and E. Schauber. 1997. Statistical power analysis in wildlife research. J. Wildl, Manage 61:270-279.

Stuart, G. 1977. The Montana frontier 1852-1864. University of Nebraska Press, Lincoln NE.

Thomas, I.D., I.J. Davidson, S. O'Donnell, and F. Brazeau. 1988. Use of track transects to measure the relative occurrence of some boreal mammals in uncut and regeneration stands. Can. J. Zool. 67:1816-1823.

Toyne, E.P. 1997. Nesting chronology of Northern Goshawks (*Accipiter gentilis*) in Wales: implications for forest management. Forestry 70:121-127.

USDA-FS 1995. Northern Flints Environmental Assessment. USDA For. Ser. Region 1, Missoula, MT.

USDA-FS. 1995. Workshop: goshawk-ponderosa pine ecosystem model testing. 24-25 May 1995. USDA For. Ser. Region 6, Dalles, OR.

USDA-FS. 1996. Boulder-Wyman Environmental Assessment. USDA For. Ser. Region 1, Missoula, MT.

USDA-FS. 1997. Workshop: ecology and management for Northern Goshawks in eastside forests of the Pacific Northwest. 27-28 Feb. 1997. Spokane, WA.

VanderWerf, E. 1993. scales of habitat selection by foraging Elepaio in undisturbed and human altered forests in Hawaii. Condor 95:980-989.

VanHorne, B. 1983. Density as a misleading indicator of habitat quality. J. Wildl. Manage. 47: 893-901.

Ward, J.M., and P.L. Kennedy. 1996. Effects of supplemental food on size and survival of juvenile Northern Goshawks. Auk 113:200-208.

Warren N.M. 1990. Old growth habitats and associated wildlife species in the northern Rocky Mountains. USDA-FS, Northern Region Wildlife Habitat Relationships Program, R1-90-42, Missoula, MT.

Whitford, T.C. 1991. Defining old-growth Douglas-fir forests of central Montana and use of the Northern Goshawk (*Accipiter gentilis*) as a management indicator species. Master's thesis, University of Montana, Missoula, MT.

Widén, P. 1997. How, and why, is the Goshawk (*Accipiter gentilis*) affected by modern forest management in Fennoscandia. J. Raptor Res. 31:107-113.

Wiens, J.A., J.T. Rotenberry, and B. Van Horne. 1987. Habitat occupancy patterns of North American shrubsteppe birds: the effects of spatial scale. Oikos 48:132-147.

Wolf, M.L., N.V. Debyle, C.S. Winchell, and T.R. McCabe. 1982. Snowshoe hare cover relationships in northern Utah. J. Wildl. Manage. 46:662-670.

Woodbridge, B., and P.J. Detrich 1994. Territory occupancy and habitat patch size of Northern Goshawks in the southern Cascades of California. Stud. Avian Biol. 16:83-87.

Yaffee, S.L. 1994. The wisdom of the Spotted Owl. Island Press, Washington, D.C.

Younk, J.V., and M.J. Bechard. 1994. Breeding ecology of the Northern Goshawk in high elevation aspen forests of northern Nevada. Stud. Avian Biol. 16:119-121.

APPENDIX A.

List of habitat variables measured and procedures used at each spatial scale.

1. **Landscape**: Distances from the nest to landscape features and areas for spatial components were calculated in GIS ArcView using layers developed by the USFS (unless noted otherwise)

   - position on slope (coded 0 = lower 1/3, 1 = middle 1/3, 2 = upper 1/3, 3 = saddle)
   - distance to permanent water source (m)
   - distance to edge of stand (m)
   - distance to nearest nonforested opening (m)
   - type of nearest nonforested opening (coded 0 = natural, 1 = clear-cut logging unit)
   - distance to any nearest road (m) (includes roads open year round and/or roads with winter/spring travel restrictions)
   - distance to nearest road open year round only (m) (excludes roads with spring/winter travel restrictions)
   - distance to nearest active goshawk nest (m)
   - slope (%) (measured within each 0.04 ha nest area plot at the upslope edge using a Suunto clinometer with percent scale)
   - aspect (coded: 0 = north, 1 = east, 2 = south, 3 = west) (determined from USGS quad maps)
   - elevation (m) (determined from USFS quad maps)

2. **Post-Fledging Family Area (PFA)**: A 170-ha circle centered on the nest, delineated in GIS ArcView using the buffer command with the nest UTM coordinate as plot center. Applicable GIS layers were then intersected with the PFA. Dbf summaries were obtained which provided the proportion of the total PFA comprised of each variable.

   - forest structural type (see Methods section, Table 1).
   - four aspect classes: north, south, east, and west
   - four canopy cover classes:
     low (0 to 25%)
     medium (25 to 50%)
     medium-high (50 to 75%)
     high (>75%)
   - three slope classes:
     low-angled slopes (0 to 20%)

medium-angled slopes (20% to 40%)
high angled slopes (> 40%)

3. **Nest Stand**

Variable radius plots (using a Relaskop at plot center with a 40 BAF factor prism) were used to calculate the following variables:

- tree density (trees/ha) by species in each of five size classes: sapling (2.54 cm to 12.70 cm dbh), pole (12.71 cm to 22.85 cm dbh), medium sawtimber (22.86 cm to 38.09 cm dbh), large sawtimber (38.10 cm to 50.8 cm dbh), extra large sawtimber (> 50.8 cm dbh).
- total tree density (sum of density in each of five size classes)
- total number of size classes (i.e. canopy layers: coded 1, 2, 3, 4, and 5)
- snags density (trees/ha > 12.71 cm dbh)
- basal area (m sq/ha) (live)

0.04-ha circular plots using the same plot center as the variable radius plot above were used to measure the following variables:

- mean tree height (m) (the average of four randomly selected trees, one in each quadrant) (measured with a Suunto clinometer with percent and 66 ft scales)
- mean height to lowest live limb (measured on each of the above selected trees with a clinometer)
- canopy closure (%) (using line-intercept sampling, Bonham [1989:108], by averaging readings from the north-south and east-west transects that divided the plot into quadrants. A 1.5 m length on either side of the nest tree on the east-west transect was excluded to avoid double counting canopy where transects cross)
- total plant ground cover (%) (calculated by averaging six Daubenmire [1959] plots, three plots randomly selected on the north-south transect and three on the east-west transect)
- forb cover (%) (same as above)
- grass cover (%) (same as above)
- wood litter (%) (same as above)
- shrub cover (%) (estimated in a 4.6 m radius plot, 1 m north of nest tree)
- number of seedlings (< 2.54 cm dbh) (counted within 0.04 ha plot)
- stand size (ha) (calculated after digitizing the stand into GIS ArcView, then using the calculate command to determine area)

4. **Nest-tree area**: Nest stand vegetative structural characteristics and methods of measurement (described above) applied at the nest area. The nest tree was plot center

for the 0.04-ha fixed-radius plot and the variable radius plot. In addition to variables measured above, the fixed radius plot was used to measure the following:

- tree density by species within each of five size classes (dbh of all trees measured in plot, then summed with each size class)
- total tree density (sum of all trees in the plot)
- basal area (m sq/ha) (calculated by summing the area of all tree boles within the plot)

5. **Nest-tree variables**:

- tree species
- diameter at breast height (cm) (measured with a standard logger's tape)
- tree height (measured with a Suunto clinometer with percent and 66 ft scales)
- height to lowest live limb (clinometer)
- height to nest (clinometer)
- nest aspect on tree (measured with a compass by standing directly below the center of nest and facing out from the tree trunk)
- tree vigor (i.e. Schmidt et al. 1976)